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16. Abstract

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INTERIM REPORT

FIELD STUDY OF A SHREDDED-TIRE EMBANKMENT

Edward J. Hoppe, P.E.
Research Scientist

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1994
VTRC 94-IR1

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ABSTRACT

This report presents interim data from the ongoing field study of an experimental shredded-tire embankment constructed near Williamsburg, Virginia. Approximately 1.7 million tires were used. This constitutes the largest reported use to date of waste tires in a structural fill in the United States. The aim of this study is to conduct a comparative performance analysis of conventional and shredded-tire embankments. The results to date indicate that the settlement of a shredded-tire embankment significantly exceeds that of a soil embankment. After construction, expansion of the shredded-tire fill was also observed.

INTERIM REPORT

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INTRODUCTION

In response to increased environmental concerns throughout the United States, the Virginia Department of Transportation (VDOT) developed an experimental project involving the use of shredded tires in a highway embankment. The Virginia Department of Environmental Quality supported this experiment by providing a $150,000 grant to offset additional construction expenses. The project represents an effort to implement a greater usage of recycled materials in construction without compromising the integrity of the final product.

Various reports indicate that approximately 2 billion waste tires are currently stockpiled across the United States, and 250 million additional units are generated each year (Tarricone, 1993). The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) mandates the use of scrap rubber in asphalt pavements. If successful, the use of shredded tires in embankments would result in an even greater volume of disposal. Some studies indicate, however, that the use of shredded tires in roadway fills may result in unacceptable pavement deflections.

PURPOSE AND SCOPE

The objective of this study is to evaluate the field performance of an experimental shredded-tire embankment designed with a 50/50 volumetric ratio of rubber to soil. In a joint effort between VDOT's Materials Division and the Virginia Transportation Research Council, an embankment containing adjoining conventional and shredded-tire sections was instrumented and monitored. The scope of this study includes an analysis of settlements, vertical stresses, construction techniques, and costs. Recently, the scope was expanded to include groundwater monitoring to assess the environmental impact of shredded tires.

METHODS

Site Description

The site is located at the intersection of the future Rte. 199 and Rte. 646 connector in York County, approximately 3 km north of Williamsburg, Virginia. The site is bordered to the north by Rte. 646 and to the east by Interstate 64. The topography of the area is flat to undulating, generally sloping in the southeasterly direction. No streams are present in the immediate vicinity. The site location map is shown in Figure 1.

The project is situated in the Coastal Plain Physiographic Province of Virginia. Geologic reports of the area (Bick, 1969) indicate sedimentary deposits of Pleistocene Age Windsor formation and Bacons Castle formation. The Windsor formation is characterized by a poorly sorted

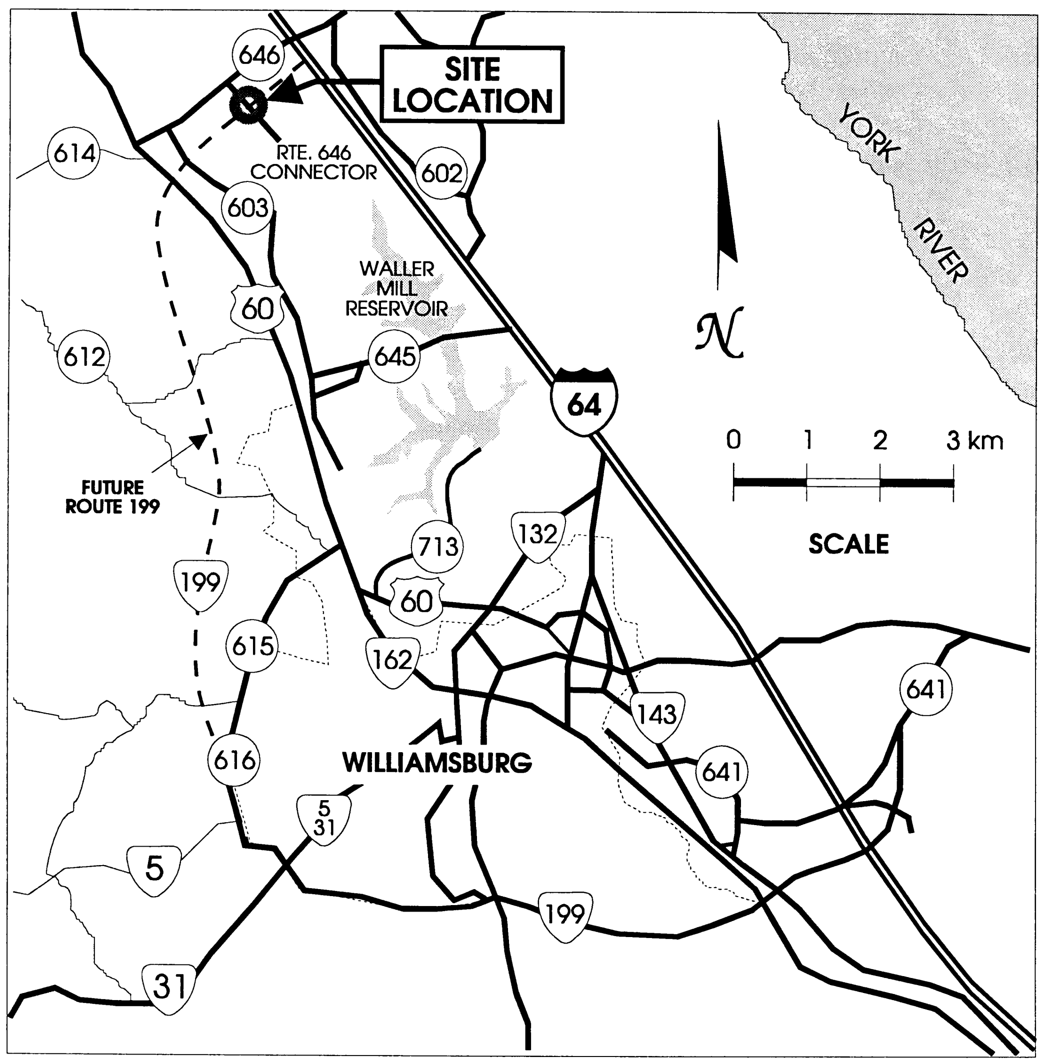

Figure 1. Site Location.

mixture of sand, silt, and clay. The Bacons Castle formation includes red sand and clay overlying gravel. These geologic formations are nearly horizontal, with a slight dip to the southeast.

Construction

In the summer of 1993, two embankments were built adjoining the Rte. 646 connector, as shown in Figure 2. One embankment contained a section of shredded tires approximately 160 m long. This embankment was constructed south of the Rte. 646 connector. The other embankment, constructed to the north, contained a section of shredded tires approximately 80 m long. Shredded-tire embankment sections were built using an approximate 50/50 volumetric ratio of rubber to soil. Specifications for a shredded-tire fill are included in Appendix A. A typical embankment cross-section is shown in Figure 3.

Site visits were conducted during construction to observe the fill placement. Shredded tires, as specified in Appendix A, were delivered by trucks with an average capacity of about 15 m^3. The supplier, Virginia Recycling Corp., was located approximately 50 km north of the site, in Providence Forge. The soil fill from the borrow area was hauled with scrapers over a distance not exceeding 1.0 km. Spreading, mixing, and compacting of soil and shredded tires were performed with bulldozers, scarifiers, and sheepsfoot rollers.

Conventional methods of compaction control, involving a nuclear density gage or a sand cone, were considered impractical since the corresponding laboratory tests on small samples of a soil/tire mix could not provide reliable data. It was decided that the compaction would be controlled by monitoring the number of passes of a compactor. Typically, a minimum of three passes of a segmented sheepsfoot roller were applied to each lift.

Data pertaining to material quantities and costs were collected from the Williamsburg Residency of VDOT, which administered the project. The construction was performed by Barnhill Contracting Company of Tarboro, North Carolina.

Future area development plans involve construction of a bridge over the Rte. 646 connector, linking both embankments. In the interim, all traffic along Rte. 199 will be routed on the four circumferential ramps, as shown in Figure 2.

Instrumentation

The instrumentation installed at the north embankment consists of two earth pressure cells and four settlement sensors interfaced with an electronic datalogger. Both the conventional and shredded-tire embankment sections were instrumented at locations B-1 and B-2, as shown in Figure 2. Earth pressure cells were installed at the base, and settlement sensors were placed at the base and the top. The earth pressure cells and settlement sensors are equipped with temperature probes. Sensor locations are indicated in Figures 4 and 5. The wiring diagram is shown in Figure 6.

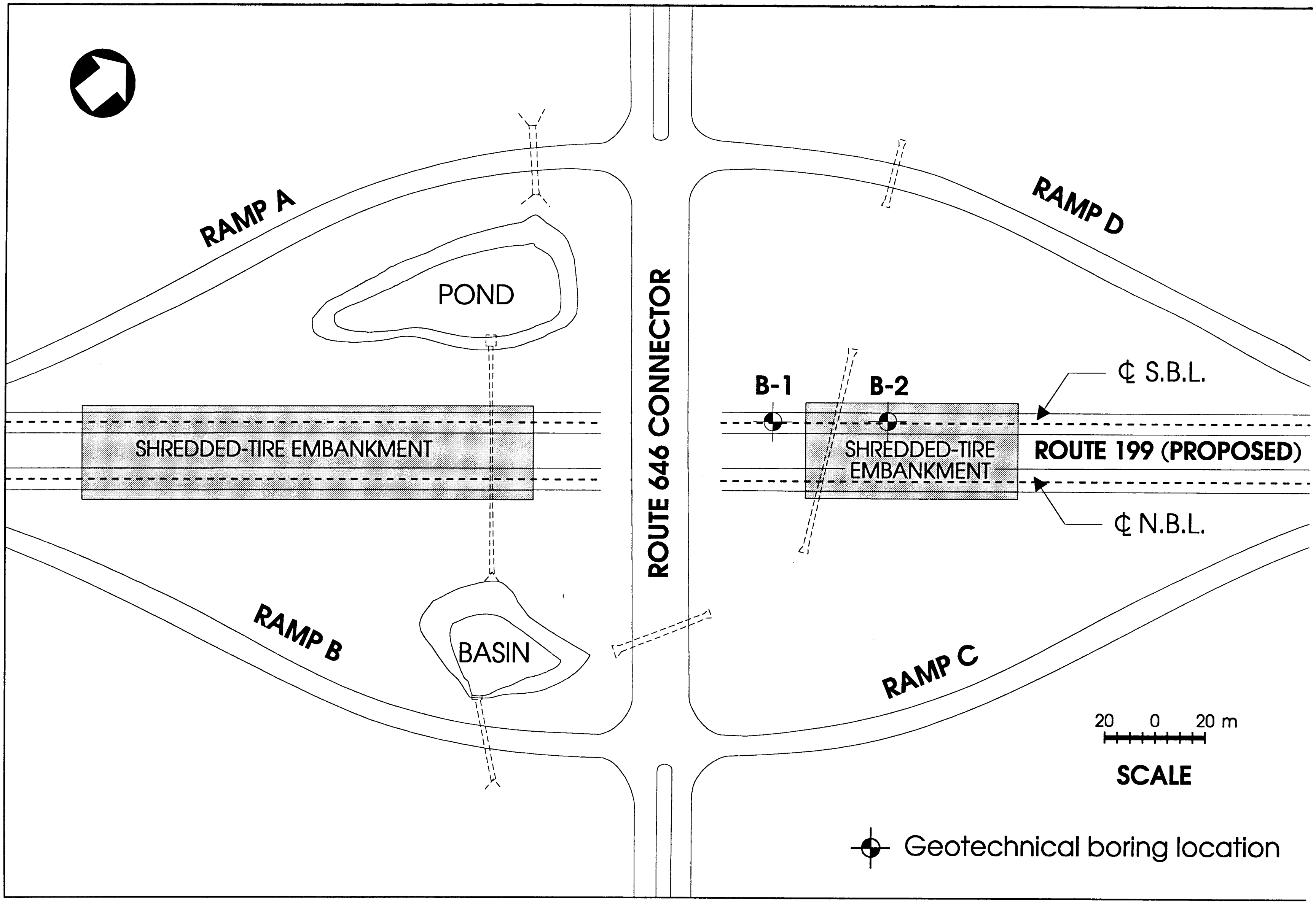

Figure 2. Project Site.

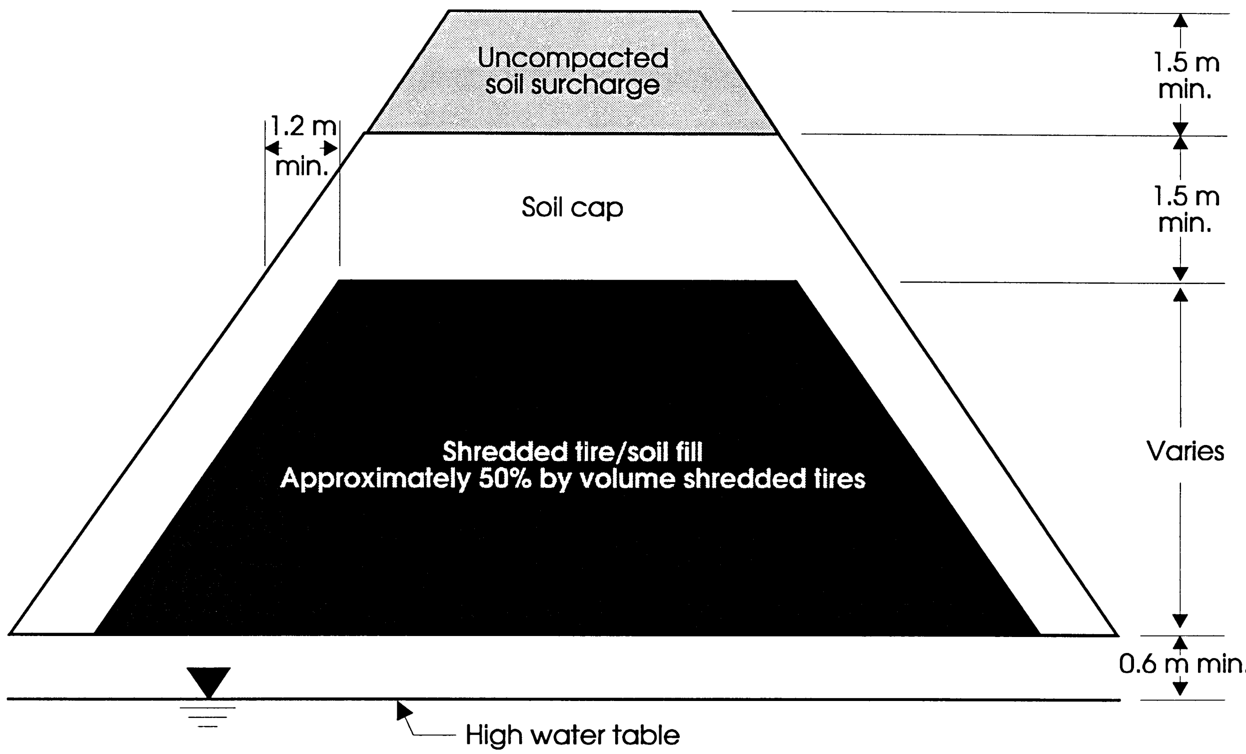

Figure 3. Cross Section of Shredded-Tire Embankment.

The purpose of the installation was to enable the long-term, remote collection of a large volume of settlement, pressure, and temperature data. All instrumentation, except for a 163 x 41 mm solar cell, is located underground. The datalogger used in the study has a NIST traceable calibration. To secure the subsurface operation, the datalogger was placed in a waterproof enclosure consisting of a section of PVC pipe. During the construction phase, data were collected at half-hour intervals. Currently, the datalogger is programmed to sample every 2 hours. All sensors are of the "vibrating wire" type to minimize the long-term drift. The principle behind a settlement sensor operation is illustrated in Figure 7. Settlement sensors are attached to 300 x 300 mm steel plates.

With the current sampling rate, the datalogger operates unattended for a period of up to 4 months, recording information on settlement, vertical pressure, and temperature. Periodically, a portable computer is connected to the datalogger and the collected data are transferred for subsequent analysis. At that time, the batteries are checked and replaced if necessary.

Prior to the embankment construction, geotechnical borings were performed in the foundation soil in the proximity of the bottom sensors to assess the existing subsurface conditions. Boring locations are indicated in Figure 2. Borings were performed to a depth of 8.1 m below the base of the embankment. The groundwater was encountered at approximately 7.0 m at the time of drilling. Undisturbed soil samples were collected for additional laboratory testing. Boring logs are included in Appendix B.

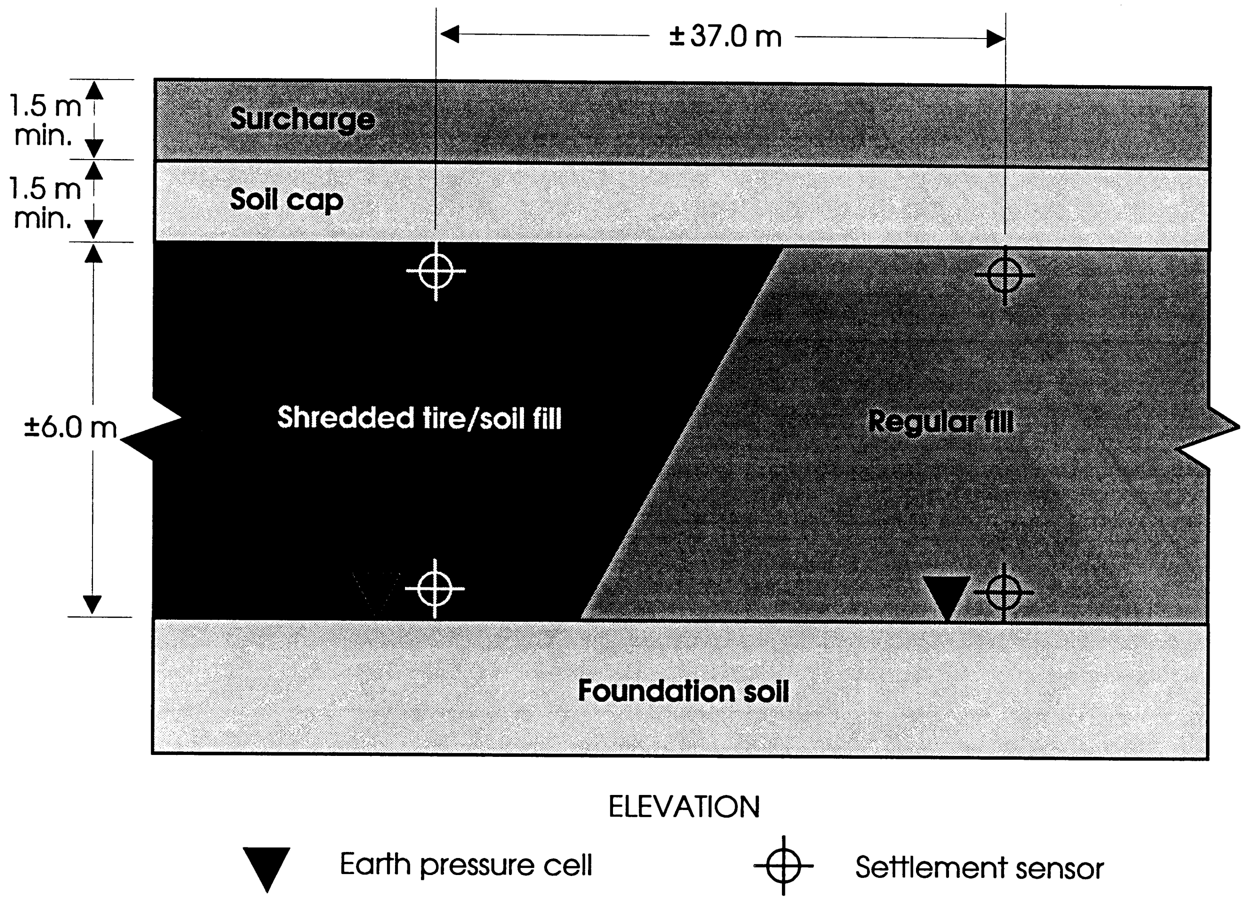

Figure 4. Elevation of Embankment.

Bottom sensors were installed in a hand-excavated trench approximately 0.6 x 0.6 x 0.5 m, which was subsequently backfilled using a light compaction effort. All cables and hydraulic lines were placed with the aid of trenching equipment at about 1.0 m below the ground surface to ensure thermal stability. Setting up the monitoring station adjacent to the embankment toe required driving two steel pipes into the foundation soil. The pipes were used to support the data-logger and hold fixed reservoirs for settlement sensors (Figure 5). Periodic elevation checks are being conducted to determine if the fixed reservoirs maintain their elevations. The upper settlement sensors were installed when the shredded-tire and soil cores reached their final elevation.

Groundwater Monitoring

The scope of the study was expanded to include groundwater monitoring for contaminants that might be leached from the tire core. One monitoring well was installed hydraulically upstream of the shredded-tire section, and one well was installed at the toe of the section. The location of the monitoring wells is shown in Figure 8. Groundwater sampling is being conducted in accordance with the Virginia Department of Environmental Quality Solid Waste Management

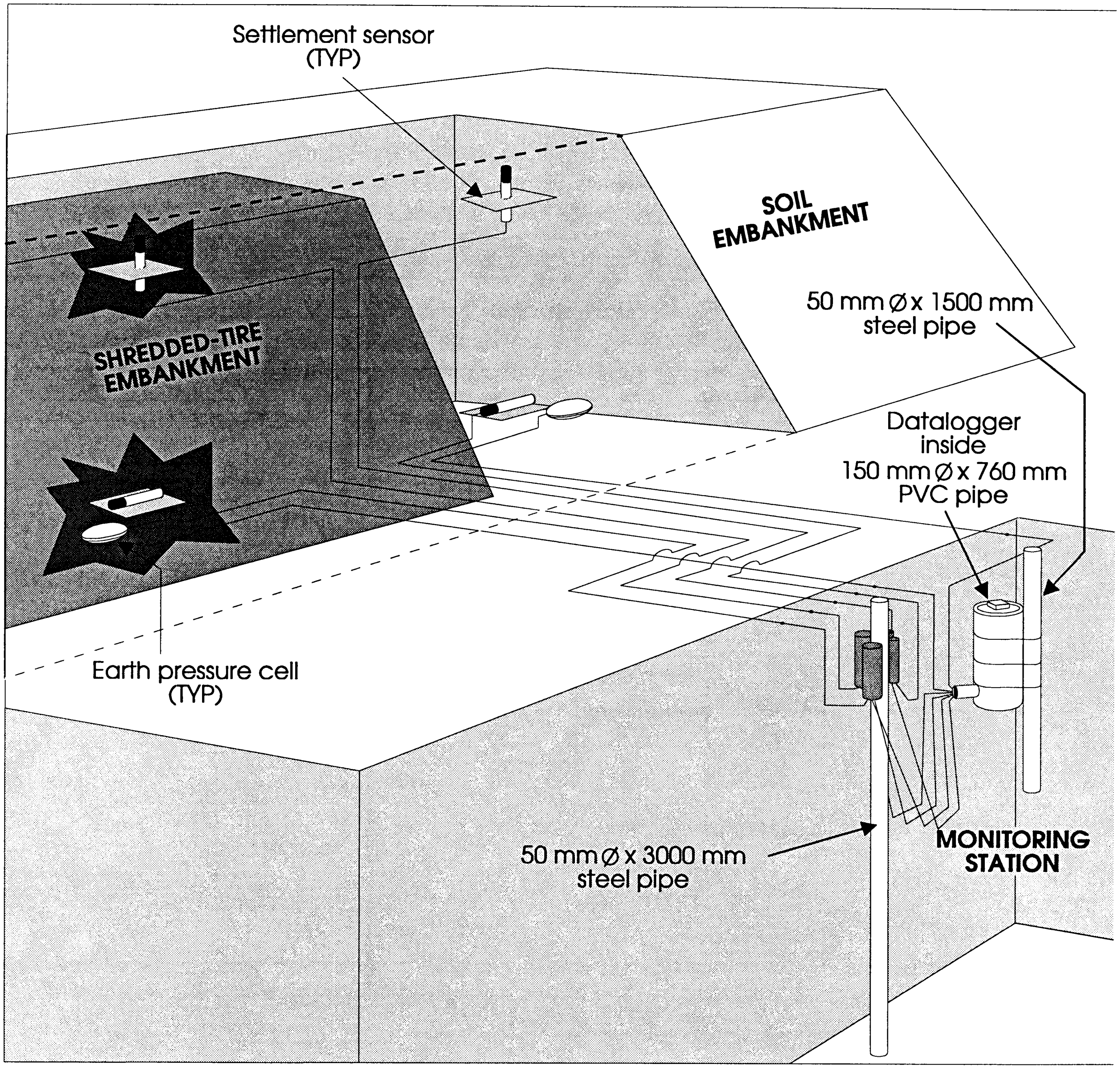

Figure 5. Instrumentation Setup.

Regulations (VR 672-20-10) pertaining to a landfill site. Testing is being performed in accordance with EPA SW-846 test methods.

INTERIM RESULTS

Project records indicate that 42,150 m^3 of shredded tires were delivered to the site. Based on existing studies, each cubic meter of loose tire chips is derived from approximately 40 tires, using an average tire mass of 10 kg (GoodYear, personal communication, 1994) and an average

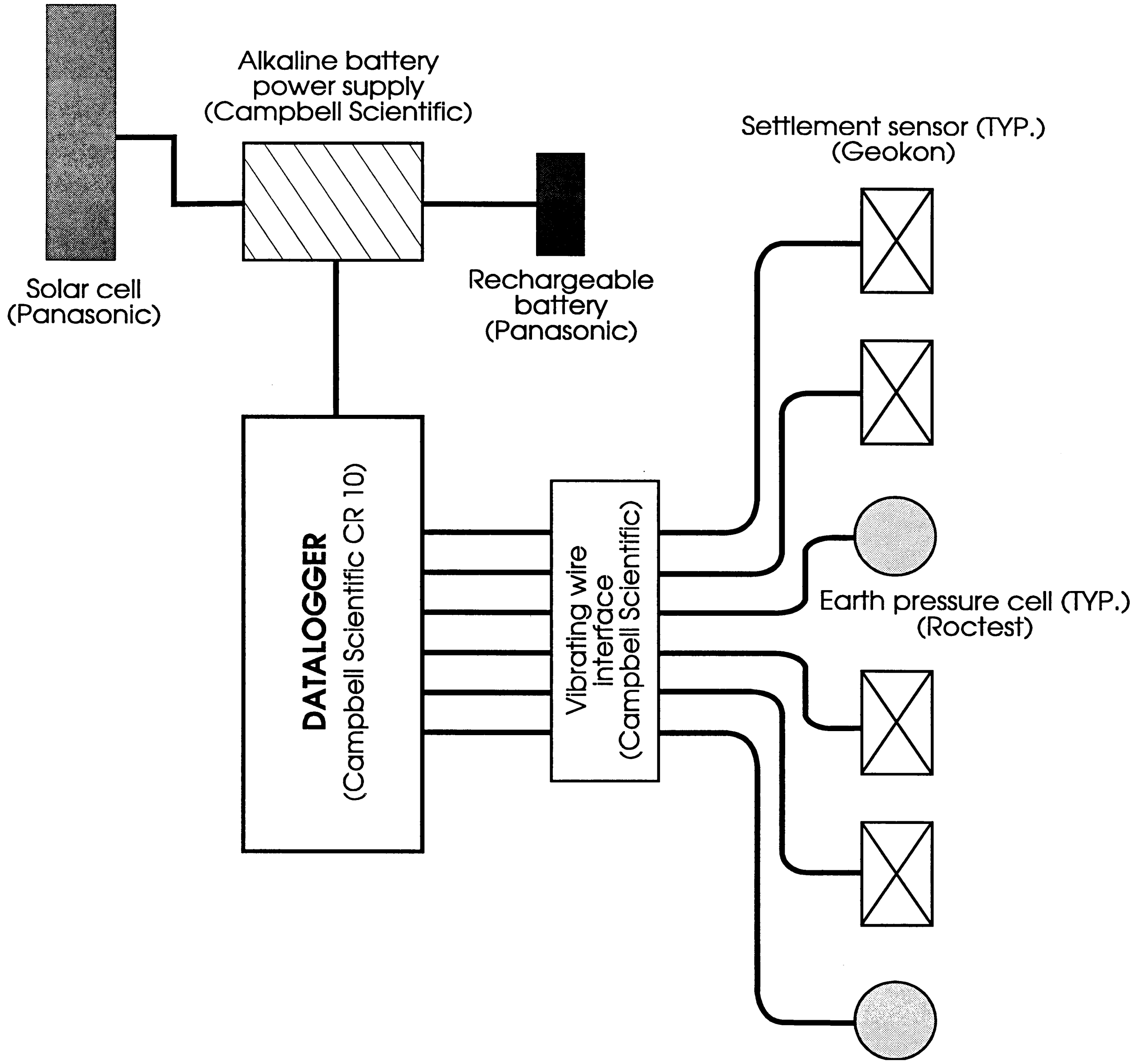

Figure 6. Wiring Diagram.

loose density of tire chips of 400 kg/m^3 (Manion & Humphrey, 1992). Thus, an estimated 1.7 million tires were used in the project, with 0.7 million in the north embankment and 1.0 million in the south embankment.

The estimated and final quantities and project costs associated with the construction within the circumferential ramps are shown in Table 1. Principal sources of the cost overrun involved the quantities of shredded tires and borrow excavation. No significant deviations from the original construction plans were reported. Project costs listed in Table 1 do not reflect the $150,000 grant from the Virginia Department of Environmental Quality.

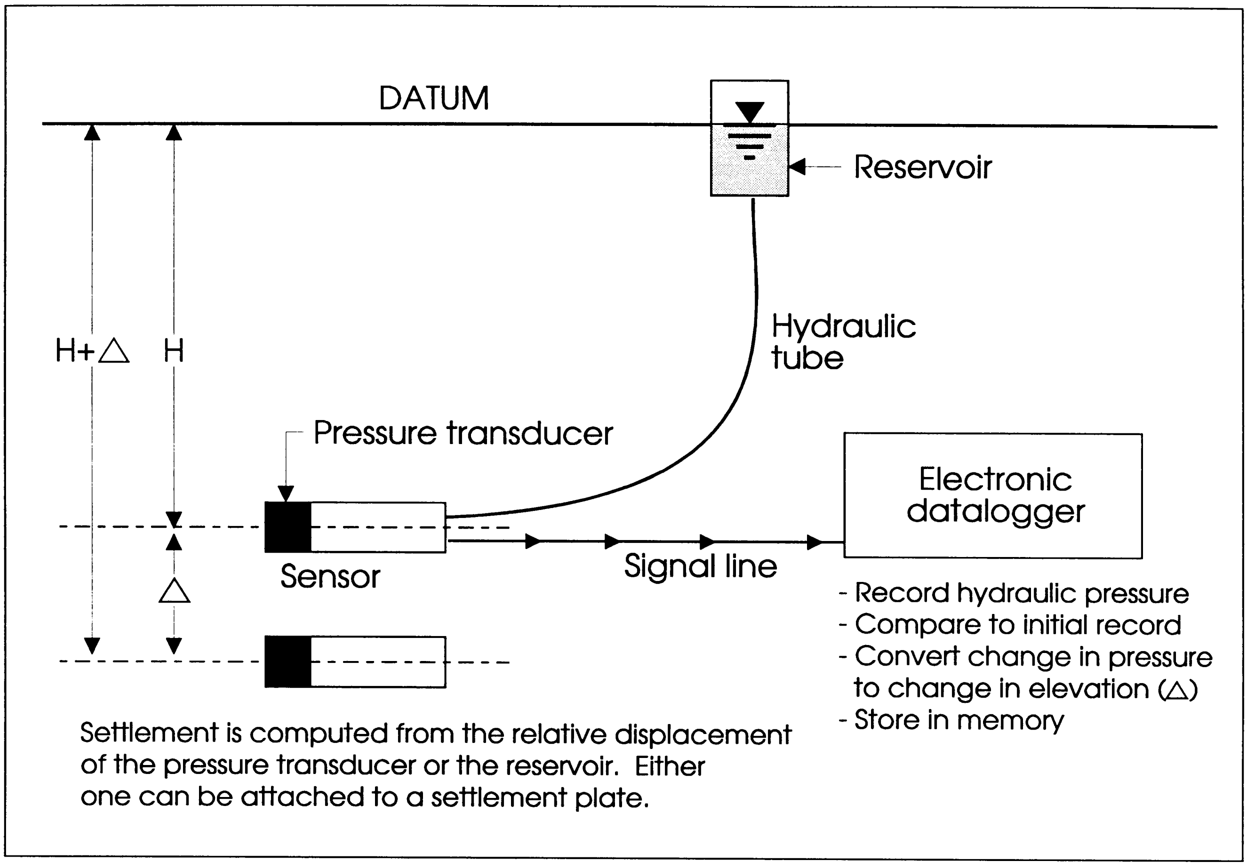

Figure 7. Settlement Sensor Operation.

The shredded-tire section was constructed with a borrow material brought to the site by scrapers and with tire chips delivered by dump trucks. The borrow material consisted mostly of a silty sand with about 20% of the particles passing the No. 200 sieve. Tire chips were spread and mixed with soil by a D-8 bulldozer and a motor grader equipped with a scarifying teeth attachment. The resulting mix had a substantially interlayered structure. A thorough intermixing of tire chips and soil appeared difficult to achieve under field conditions. The thickness of each lift prior to compaction was about 0.6 m. It is estimated that approximately 90% of the tire chips met the required material specifications (Appendix A). Some oversized shreds were observed on site.

The rate of construction of the shredded-tire section was found to be essentially the same as that of the regular section. Since the only requirement for compaction of each lift was three passes of a sheepsfoot roller, the construction proceeded at a rapid pace. No major problems relating to vehicle tires being punctured by the steel belts protruding from tire chips were reported. Visual observations of the construction activities did not indicate a need for specialized equipment or methods.

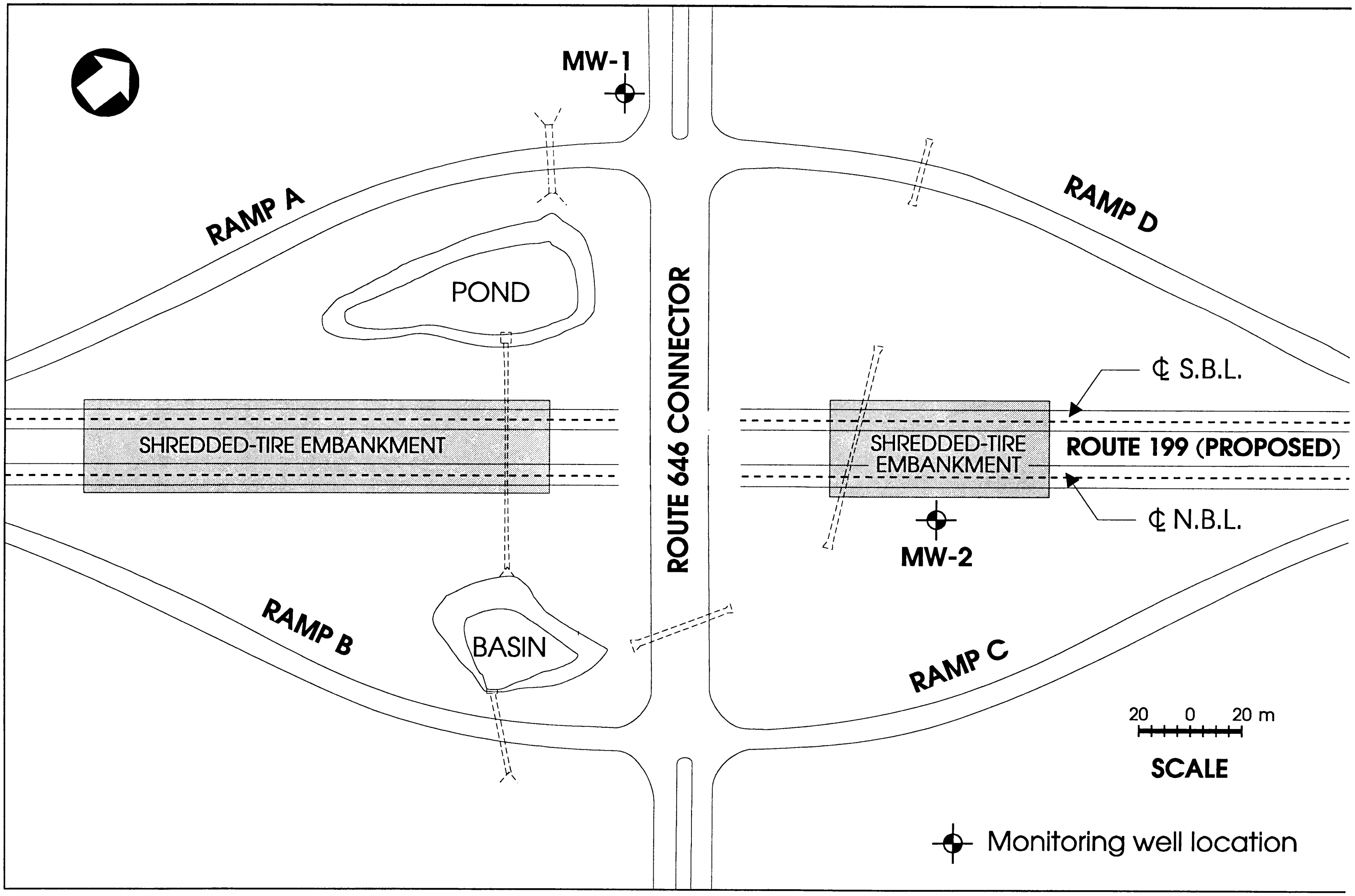

Figure 8. Location of Monitoring Wells.

Table 1
MATERIAL QUANTITIES AND PROJECT COSTS

Item	Estimated Quantity	Final Quantity	Units	Unit Price	Cost
North Embankment					
Construction Survey			L.S.	$2,625.00	$ 2,625
Surplus Regular Excavation	18,809	21,318	m^3	1.6021	34,153
Borrow Excavation	10,972	16,143	m^3	9.8640	159,234
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	9,091	18,029	m^3	10.3701	186,966
Surcharge	4,261	8,632	m^3	9.8640	85,150
South Embankment					
Construction Survey			L.S.	2,625.00	2,625
Surplus Regular Excavation	27,067	30,677	m^3	1.6021	49,147
Borrow Excavation	15,789	26083	m^3	9.8640	257,280
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	13,082	24,119	m^3	10.3701	250,112
Surcharge	8,555	9,570	m^3	9.8640	94,396
Total Final Cost (as of 3/11/94):					**$1,129,688**
Total Estimated Cost (Work Order #2, 5/12/93):					**$ 704,179**
Cost Overrun:					**$ 425,509**

The settlement of the foundation soil and the vertical stress exerted by the embankment on the foundation soil have been monitored from the outset of construction. Both sections of the embankment have been monitored. Appendix C contains the results of settlement, vertical stress, temperature at the base elevation, and temperature at the monitoring station approximately 1 m below the ground surface. Data were collected at half-hour intervals during construction and at 2-hour intervals thereafter. At the end of construction, the upper settlement sensors were activated and all settlement readings were re-zeroed to indicate simultaneously postconstruction settlements of the top of the embankment and the foundation soil. The results included in Appendix C cover the period of 7/12/93 to 11/20/93.

DISCUSSION

The amount of shredded tires used on the project (42,150 m^3) substantially exceeds the quantities reported in previous case studies (ENR, 1993). This project constitutes the largest use of shredded tires to date in highway construction in the United States.

The compacted unit weight of shredded tires usually ranges from 3.1 to 7.1 kN/m^3, with an average value of 5.1 kN/m^3 (Ahmed, 1993). A typical compacted unit weight of a soil fill used on the project is about 17.3 kN/m^3. The resulting 50/50 soil/tire mix has a compacted unit weight of approximately 11.2 kN/m^3. Thus, the vertical stress exerted by a shredded-tire embankment is expected to be approximately 65% of the stress exerted by a soil embankment of the same geometry.

Boring logs included in Appendix B indicate that the subsurface soil underlying the shredded-tire section (Boring B-2) is more compressible than the soil underlying the conventional section (Boring B-1). This difference in compressibility must be accounted for when comparing the respective base settlements. Applying Schmertmann's method, it may be estimated that the soil represented by Boring Log B-2 would compress approximately 3 times as much as the soil represented by Boring Log B-1 under identical loading conditions. Thus, accounting for both the unit weight and the nonuniformity of the subsurface, the expected base settlement under the shredded tires is about 1.9 times the settlement under the soil section.

Final base settlements recorded at the end of the embankment construction were 132 mm and 112 mm under the shredded-tire and soil sections, respectively (Appendix C). The resulting ratio is 1.2, as compared with the expected value of 1.9.

Postconstruction embankment settlements differed significantly. Approximately 6 days after completion of the surcharge placement, the settlement of the top of the tire core had stabilized at about 150 mm (upper sensor). In the following period of approximately 68 days, the tire core underwent a vertical expansion of about 80 mm, with a resulting net settlement of 70 mm. The latest records indicate renewed compression, with a most recent settlement of about 110 mm. Some vertical movement was also detected by the base sensor, but it generally fluctuated in a relatively narrow range of about 110 to 120 mm. A possible explanation for this behavior is the relaxation and readjustment of individual tire chips following the initial compression during placement. At the same time, the top of the soil section maintained a settlement of about 40 mm. Thus, the latest records indicate that the top of the shredded-tire section has settled about 2.75 times as much as the top of the soil section (110/40).

A load test was conducted at the end of construction and prior to surcharge placement to assess the relative compressibilities of each section. A Caterpillar D-9G dozer with a mass of approximately 30 tons was stationed over the sensor locations for a period of 15 minutes. Simultaneously, the settlement sensors were set to collect data at a rate of 1 sample per minute. No effect on settlement was detected by the bottom sensors. Also, no influence was detected by the top sensor placed in the soil section. The top sensor in the shredded-tire section, however, recorded a recoverable deformation of about 2 mm, indicating a more compressible structure. The corresponding vertical stress at the center of the tire core was approximately 7 kPa, based on the Boussinesq stress distribution.

Vertical stresses acting at the base of the embankment followed significantly different patterns for soil and shredded tires. A steady increase in the vertical stress was observed during the construction of the soil section. After about 2 days of construction of the shredded-tire section, the vertical stress dropped off slightly and then stabilized. After construction, it has been increasing gradually. The observed vertical stresses are approximately 50% lower than would be expected by multiplying the embankment height by the unit weight of a fill material. This may be explained by the phenomenon of stress transfer or arching taking place within the embankment undergoing a base settlement. The latest records indicate vertical stresses of about 32 and 85 kPa under the shredded-tire and soil sections, respectively. This constitutes a ratio of 0.4, as compared with the expected value of 0.65.

The embankment base temperature has been essentially the same at both sections over a time period represented by the current data (Appendix C). The temperature at the monitoring station has been decreasing steadily due to the proximity of the sensor to the ground surface and the corresponding period of cooler ambient temperatures. Long-term temperature monitoring will allow an assessment of the rate of heat transfer through shredded tires and soil. It is also expected to provide data on the potential use of shredded tires as a thermal insulation material.

The groundwater monitoring program is currently at the stage of acquiring a statistical baseline. Monitoring wells will be sampled at quarterly intervals for the first year of operation. The subsequent groundwater sampling will be conducted semiannually.

Future work related to this project will include continued data collection and analysis. The environmental concerns, specifically the potential generation of hazardous leachates, will be addressed with a groundwater monitoring program. The embankment instrumentation is expected to remain operational when the surcharge is ultimately removed and the road is open to traffic. Periodic interim reports will be issued as additional field data are compiled.

CONCLUSIONS

1. Three months after the end of construction, the settlement of the shredded-tire section was over twice that of the conventional section.

2. Vertical expansion of the shredded-tire section was observed following the end of construction. Approximately 80 mm of expansion was recorded.

3. Vertical stresses exerted at the base of the shredded-tire section are approximately 40% of the corresponding values recorded at the conventional embankment. Given the identical subgrade soil conditions, the relative magnitudes of base settlements would be of the same proportion.

4. Final project costs appear to indicate that the use of shredded tires to replace a regular borrow material may not be economically advantageous. The unit cost of shredded tires was approximately 5% greater than the unit cost of a borrow excavation; however, shredded tires were paid for according to a loose volume, whereas the regular soil fill was paid for according to an in-place volume. Since approximately 30% compression occurred during placement, the effective in-place unit cost of shredded tires was about 37% greater than the corresponding

unit cost of regular fill. It should be noted, however, that the costs associated with this particular project stemmed from a work order and thus may not truly reflect long-term market conditions.

5. A number of situations might arise where the use of shredded tires would be justified on technical merits. Potential applications requiring further research include the following:

   — lightweight fill to reduce the settlement of poor foundation soils

   — pipe backfill to reduce soil pressures exerted on buried pipes

   — backfill at integral bridges to reduce active earth pressures at abutments.

ACKNOWLEDGMENTS

The author thanks Messrs. Stan Hite and Bob Horan of VDOT's Materials Division for their assistance during the course of the study and Ms. Wendy Ealding for coordinating the groundwater sampling activities. In addition, the author expresses his gratitude to Mr. Jeff Tabrizi of VDOT Suffolk District for conducting geotechnical drilling and installing monitoring wells. Thanks are also extended to Mr. Wayne Rimmer of VDOT's Richmond District for providing trench excavation services during the sensor installation. The technical support from Messrs. Jim French and Art Wagner of the Research Council, graphics assistance from Mr. Randy Combs, and the editing effort on the part of Ms. Linda Evans are greatly appreciated. This study is supported by HPR funds from the FHWA.

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APPENDIX A

Shredded-Tire Fill Specifications

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
SHREDDED SCRAP TIRE LIGHTWEIGHT FILLS

February 3, 1994

I. DESCRIPTION

These specifications cover the construction of lightweight fills using shredded scrap tires. The placement of shredded scrap tires shall be in areas of embankment as detailed in Section III herein.

II. MATERIALS

Shredded scrap rubber shall be cut from any type tires and by any method that will meet the following requirements:

A. The average size of shredded scrap rubber shall not exceed 40 sq. in. (determined from average of 10 samples).
B. The maximum length of any piece shall be 10 in.
C. All pieces shall have at least one sidewall severed from the face of the tire.
D. No metal particles shall be placed in the fill that are not firmly attached to a rubber segment.

Stockpiling of shredded scrap tires will not be permitted on the project site. Shredded scrap tires shall be transported from the processing site and placed directly in the embankment.

III. CONSTRUCTION PROCEDURES

The shredded scrap tires shall be blended with soil within the following boundaries in the embankment:

A. Bottom - minimum two feet (2') above the high water table.
B. Sides - minimum four feet (4') inside the side slopes.
C. Top - minimum 5 foot (5') soil embankment "cap."

The embankment sections shall be constructed with a crown of not less than 3/4 inch per foot away from the centerline of the fill. If the soil and tire fill becomes saturated during construction, drainage ditches shall be constructed to dry the material before proceeding.

Embankments shall be constructed by placing alternate layers of shredded tires and soil and mixing and blending during compaction. The thickness of uncompacted layers of shredded tires and soil shall be as directed by the Engineer. For those areas where shredded tires are to be incorporated into the embankment, shredded tires shall constitute approximately fifty percent (50%) by volume of that portion of the embankment. The soil and tire embankment shall be manipulated sufficiently to minimize voids.

(Continued)

Manipulation and compaction of the soil and tire embankment shall be to the satisfaction of the Engineer, and shall be accomplished with a sheepsfoot roller or other approved method.

Soil embankment "cap" shall be compacted in accordance with Section 303 of the Specifications.

A five (5') minimum uncompacted surcharge shall be placed on top of the "cap" as detailed on the plans. Surcharge shall remain in place for the time period sspecified on the plans or until removal is authorized by the Engineer.

Settlement plates shall be placed as detailed on the plans and according to Section 303.04 of the Specifications.

IV. METHOD OF MEASUREMENT AND BASIS OF PAVEMENT

Shredded scrap tires will be paid for at the contract unit price per ton, which shall be full compensation for furnishing tires and for placing, manipulation and compaction.

Surcharge placement and removal will be measured and paid for in accordance with Section 303.06 of the Specifications.

Settlement plate will be measured and paid for in accordance with Section 303.06 of the Specifications.

Payments will be made under:

Pay Item	**Pay Unit**
Shredded Scrap Tires	Ton
Surcharge Placement and Removal	Cubic Yard
Settlement Plate	Each

APPENDIX B

Boring Logs

V · I · R · G · I · N · I · A

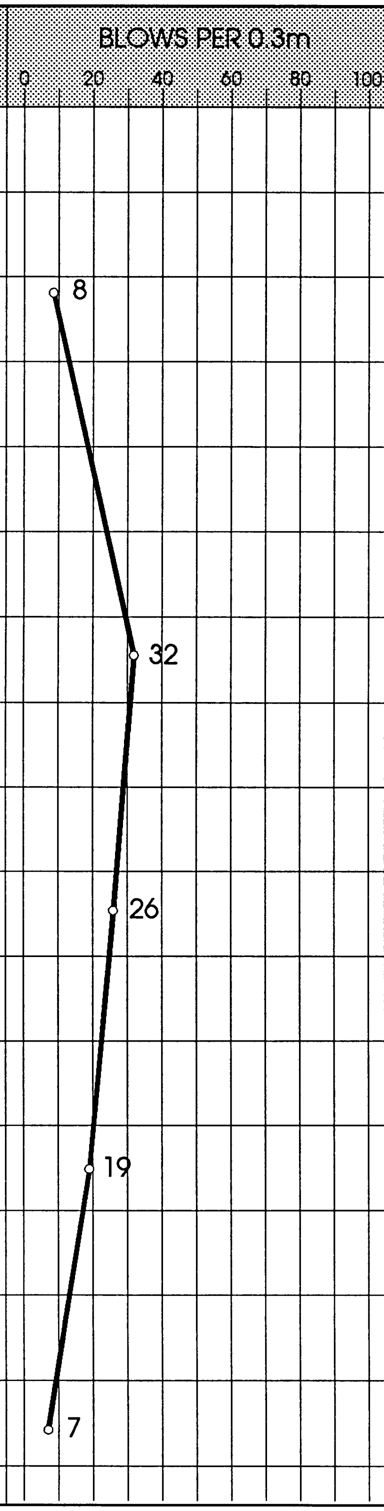
TRANSPORTATION RESEARCH COUNCIL

BORING LOG NO. B-1

PROJECT: RTE. 199 - Williamsburg

LOCATION: STA. 451+80

DATE DRILLED: July 9, 1993
ENG./GEO.: Edward Hoppe
DRILLER: VDOT - Suffolk District
DRILLING METHOD: 57 mm ID Hollow Stem Auger, 63 kg Hammer
SURFACE ELEVATION: Base of embankment
TOTAL DEPTH: 8.1 m
DEPTH TO WATER: 7.0 m



ELEV (m)	DEPTH (m)	DESCRIPTION	REMARKS
		Approximately 1m of fill - silty SAND	
	1.0	Loose, tan, silty, fine SAND, moist to dry (SM)	Shelby tube @ 1.4 - 2.0 m
	2.0		
	3.0	Becomes dense, moist	
	4.0	Becomes medium dense, light gray	
	5.0		
	6.0	Becomes moist to damp, some clay	
	7.0	Becomes saturated	
	8.0		Boring terminated at 8.1 m and backfilled upon completion

V · I · R · G · I · N · I · A

VTRC

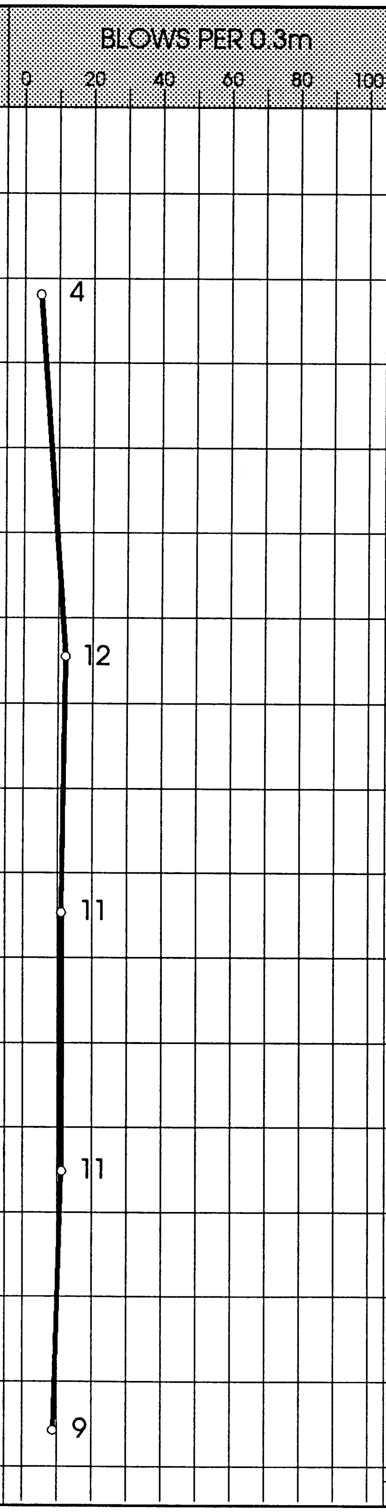
TRANSPORTATION RESEARCH COUNCIL

BORING LOG NO. **B-2**

PROJECT: RTE. 199 - Williamsburg

LOCATION: STA. 453+00

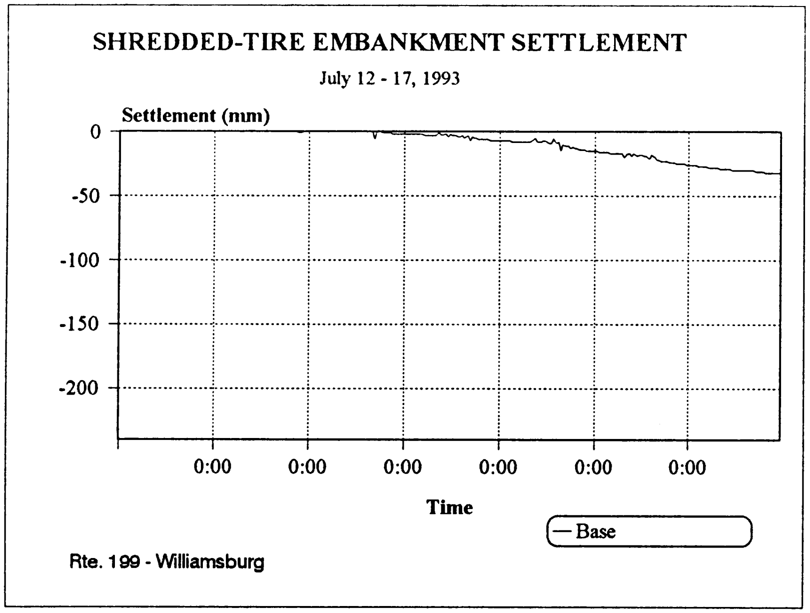
DATE DRILLED: July 9, 1993
ENG./GEO.: Edward Hoppe
DRILLER: VDOT - Suffolk District
DRILLING METHOD: 57 mm ID Hollow Stem Auger, 63 kg Hammer
SURFACE ELEVATION: Base of embankment
TOTAL DEPTH: 8.1 m
DEPTH TO WATER: 7.0 m

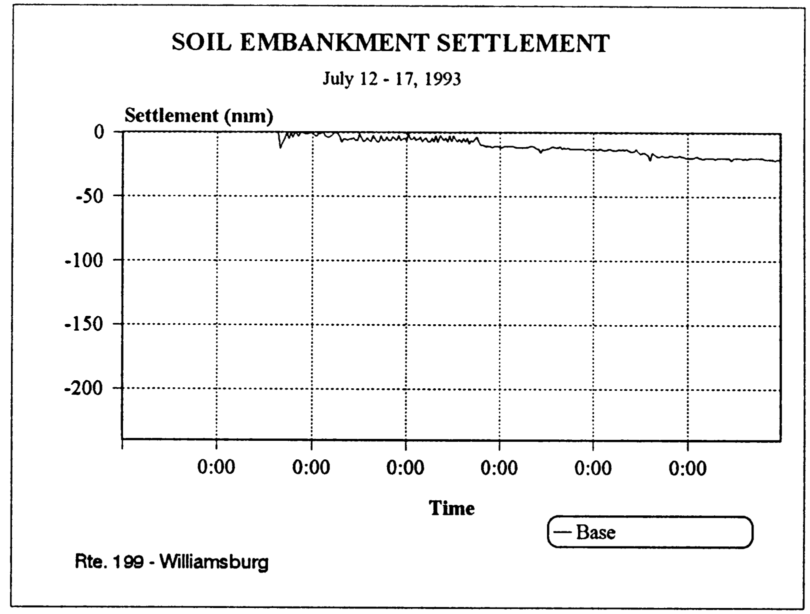


ELEV (m)	DEPTH (m)	BLOWS PER 0.3m	DESCRIPTION	REMARKS
	0.0–1.0		Approximately 1m of fill - silty SAND	
	1.0–2.2	4	Soft, tan, lean CLAY with trace of gravel, trace of organics, moist (CL)	Shelby tube @ 1.4 - 2.0 m
	2.2–3.0		Soft, tan, sandy SILT, moist (ML)	Shelby tube @ 2.1 - 2.7 m
	3.0–4.0	12	Becomes stiff, light gray, percentage sand increasing.	
	4.0–6.0	11	Medium dense, tan, silty SAND, moist (SM)	
	6.0–7.5	11	Becomes moist to wet	
	7.5–8.1	9	Becomes loose, saturated, coarse	Boring terminated at 8.1 m and backfilled upon completion

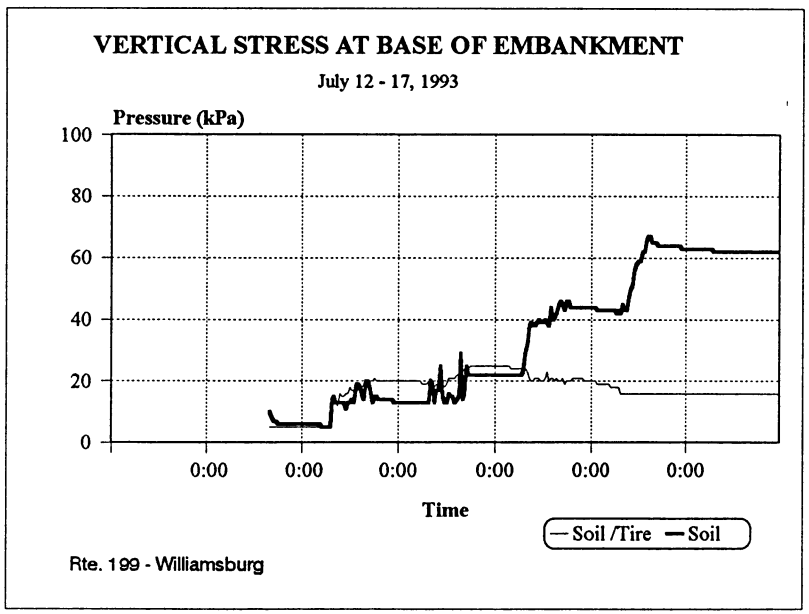
APPENDIX C

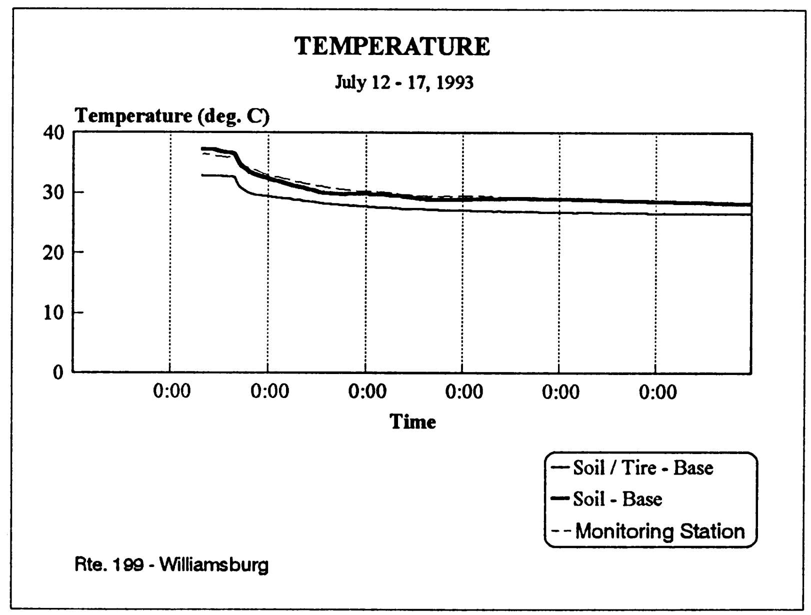
Results of Field Monitoring

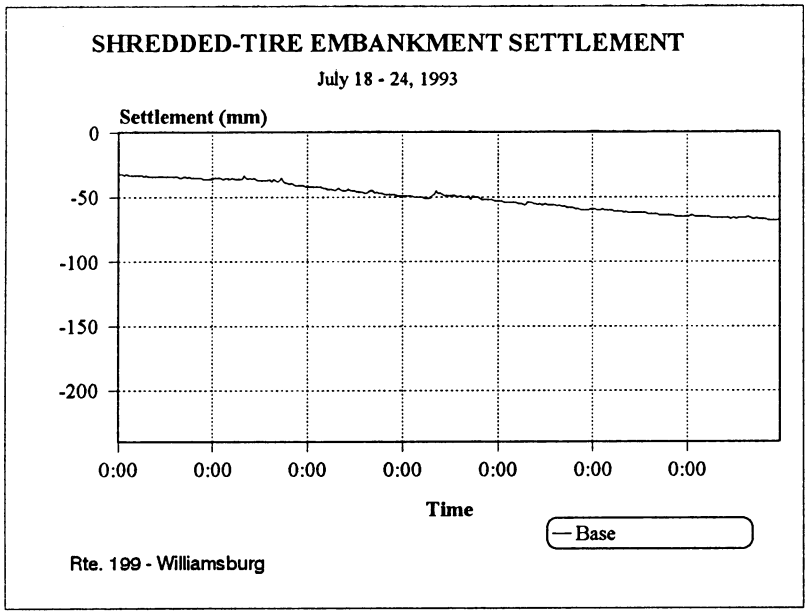


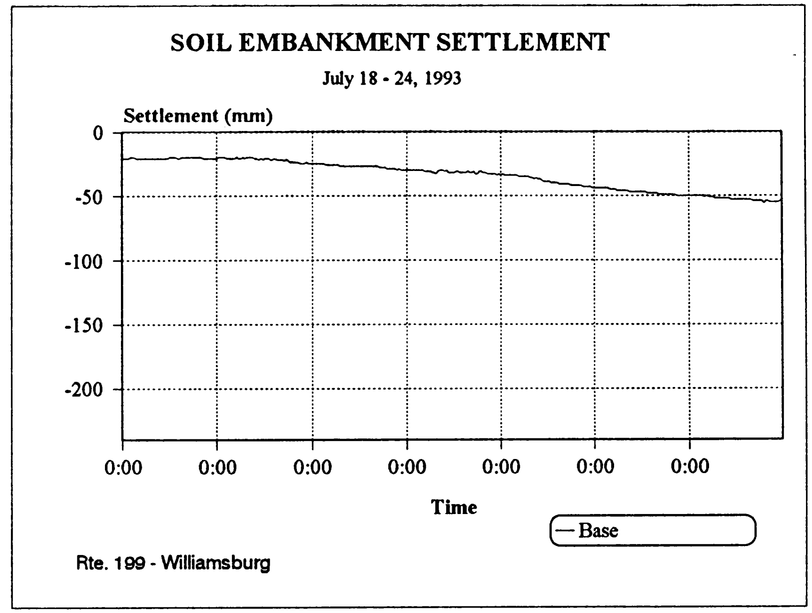


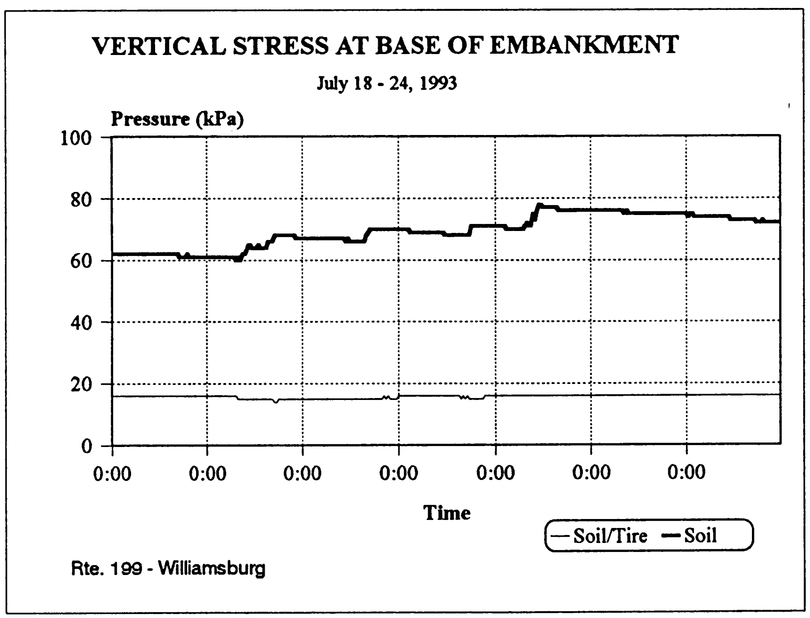
Note: Sensors installed on 7/12/93. Embankment construction began on 7/13/93. Time 0:00 corresponds to midnight.

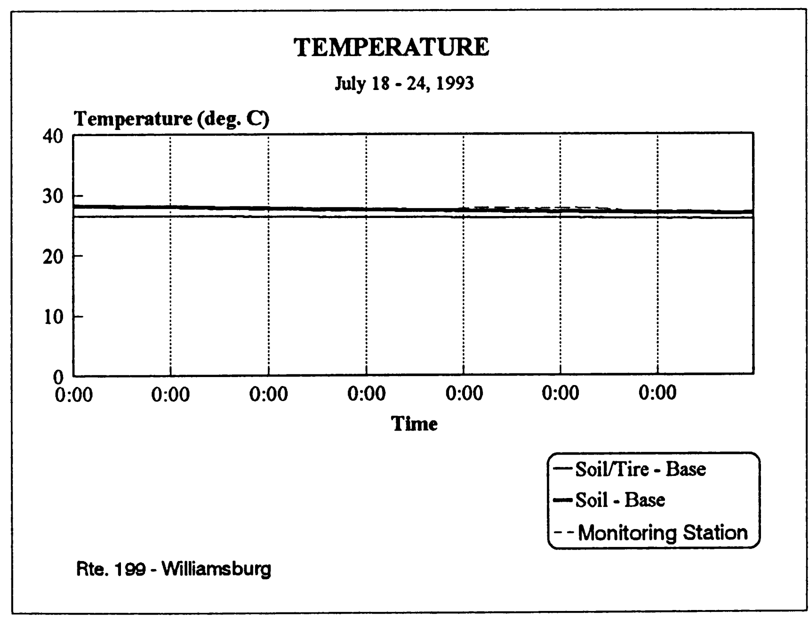


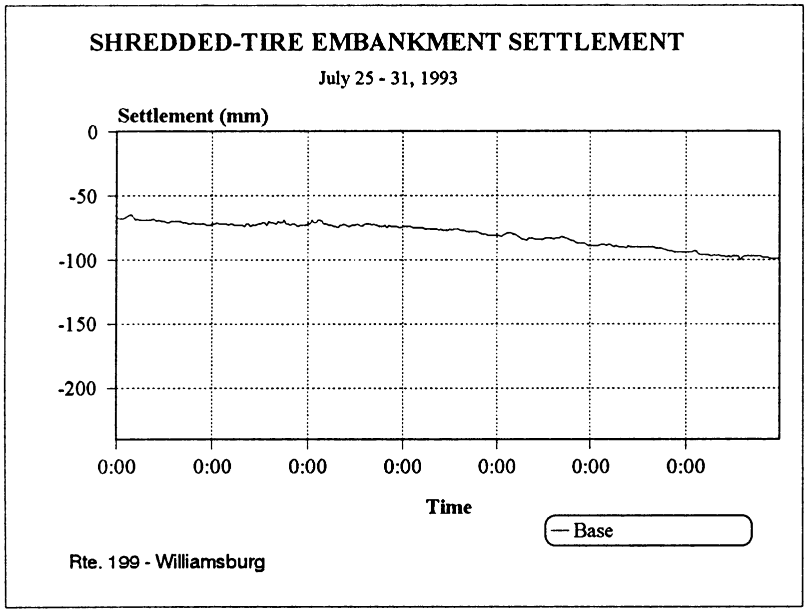


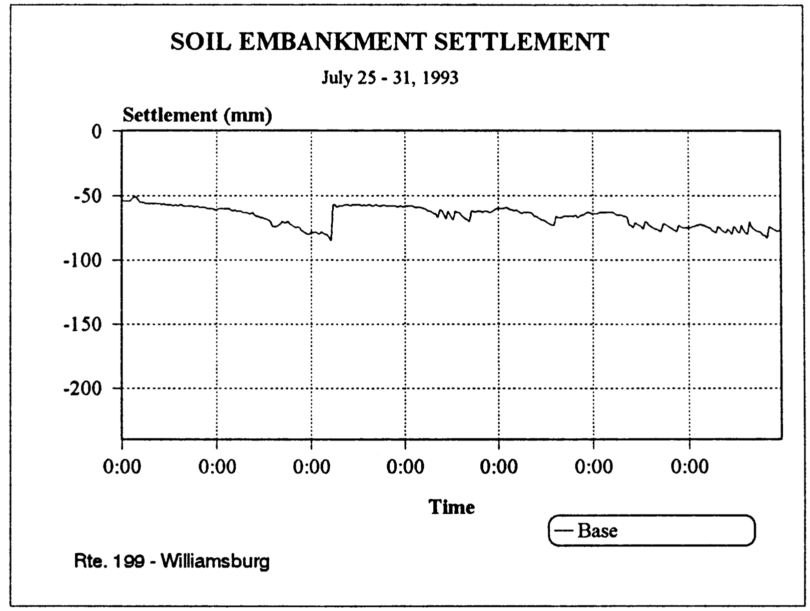

SHREDDED-TIRE EMBANKMENT SETTLEMENT
July 18 - 24, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Rte. 199 - Williamsburg

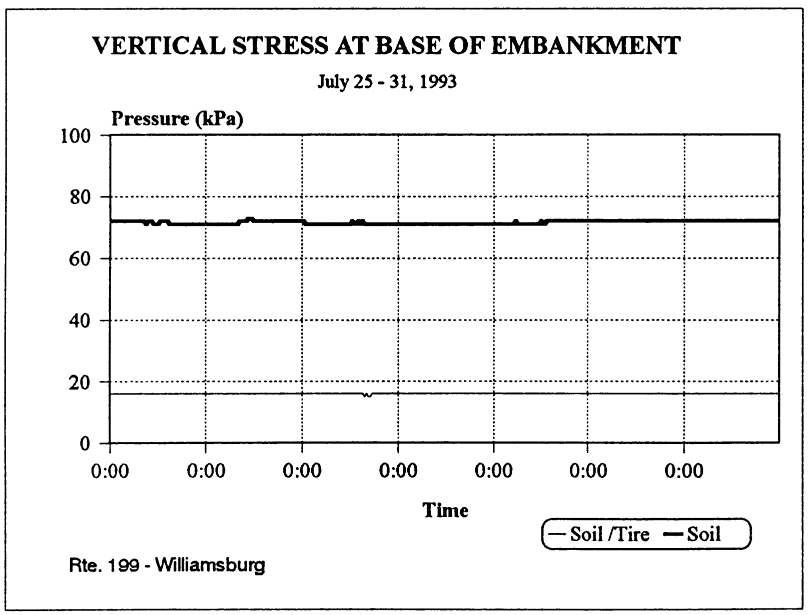

SOIL EMBANKMENT SETTLEMENT
July 18 - 24, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Rte. 199 - Williamsburg

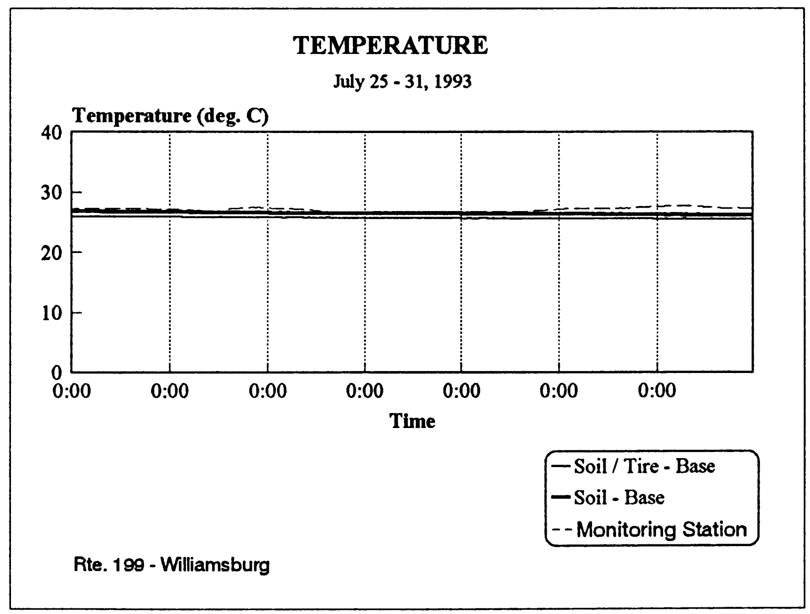

VERTICAL STRESS AT BASE OF EMBANKMENT
July 18 - 24, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

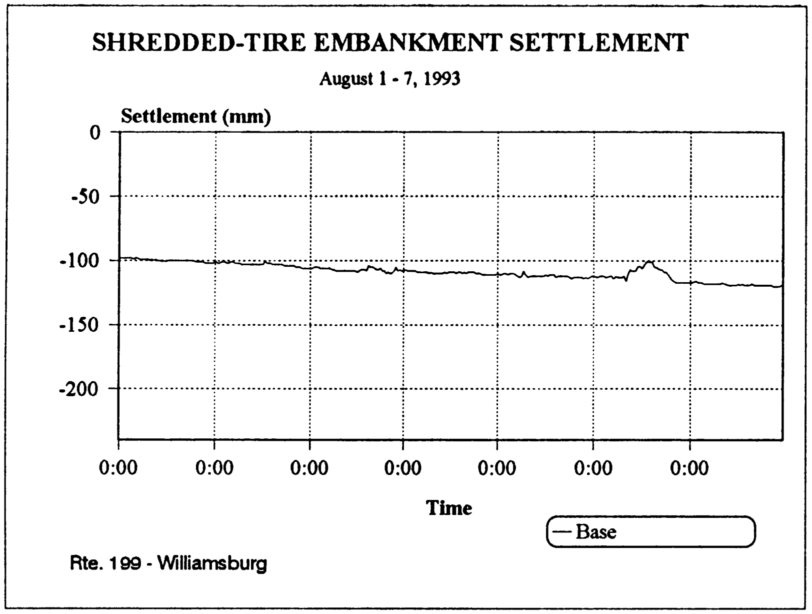

TEMPERATURE
July 18 - 24, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

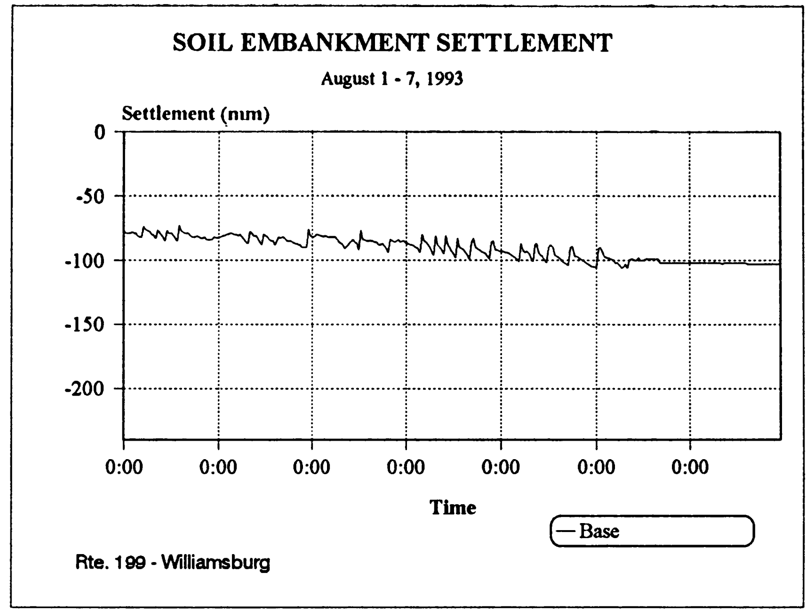

SHREDDED-TIRE EMBANKMENT SETTLEMENT
July 25 - 31, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Rte. 199 - Williamsburg

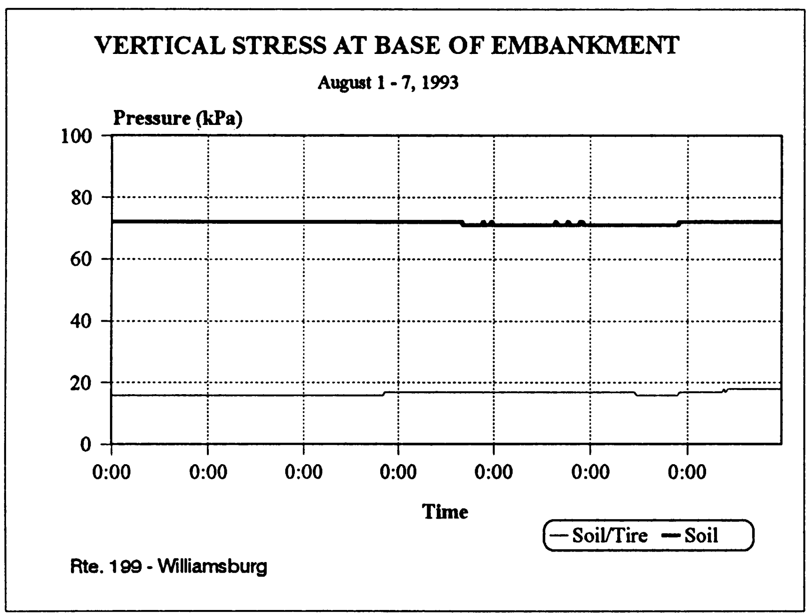

SOIL EMBANKMENT SETTLEMENT
July 25 - 31, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Rte. 199 - Williamsburg

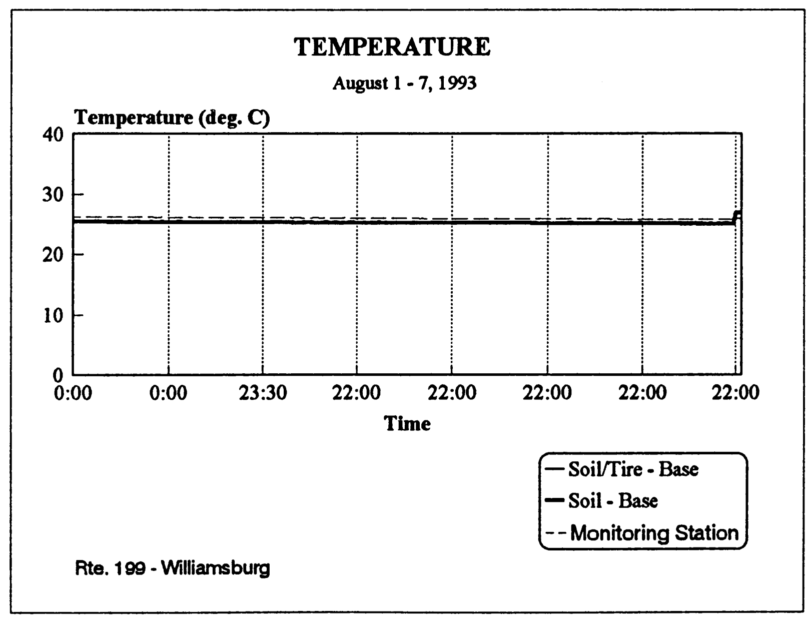

VERTICAL STRESS AT BASE OF EMBANKMENT
July 25 - 31, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil /Tire
Soil
Rte. 199 - Williamsburg

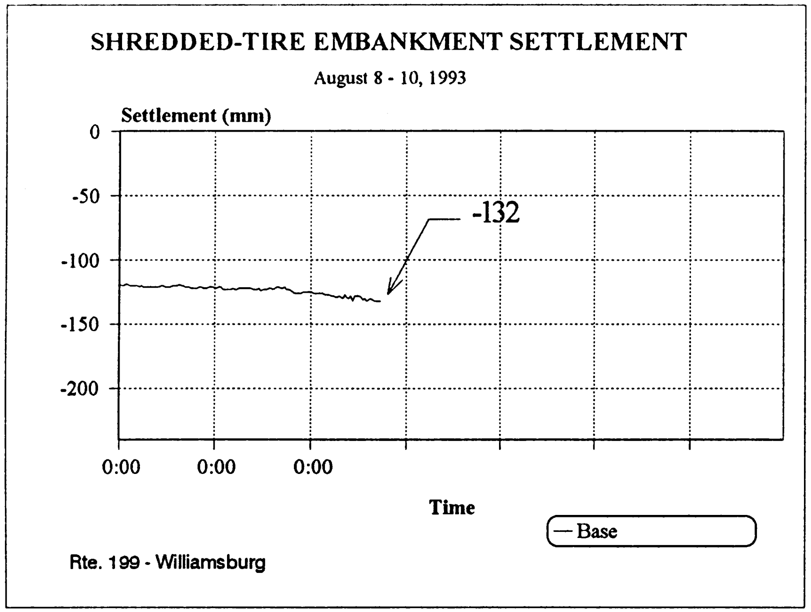

TEMPERATURE
July 25 - 31, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

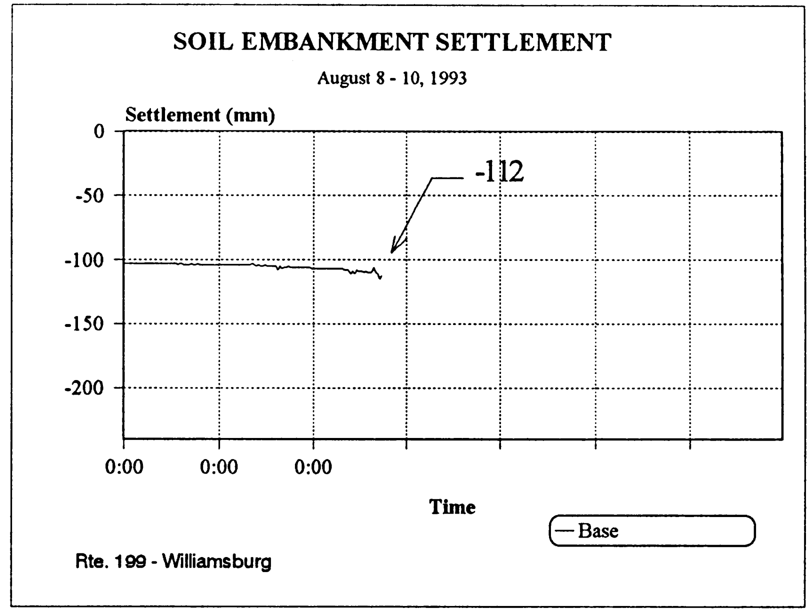

SHREDDED-TIRE EMBANKMENT SETTLEMENT
August 1 - 7, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Base
Rte. 199 - Williamsburg


SOIL EMBANKMENT SETTLEMENT
August 1 - 7, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Base
Rte. 199 - Williamsburg

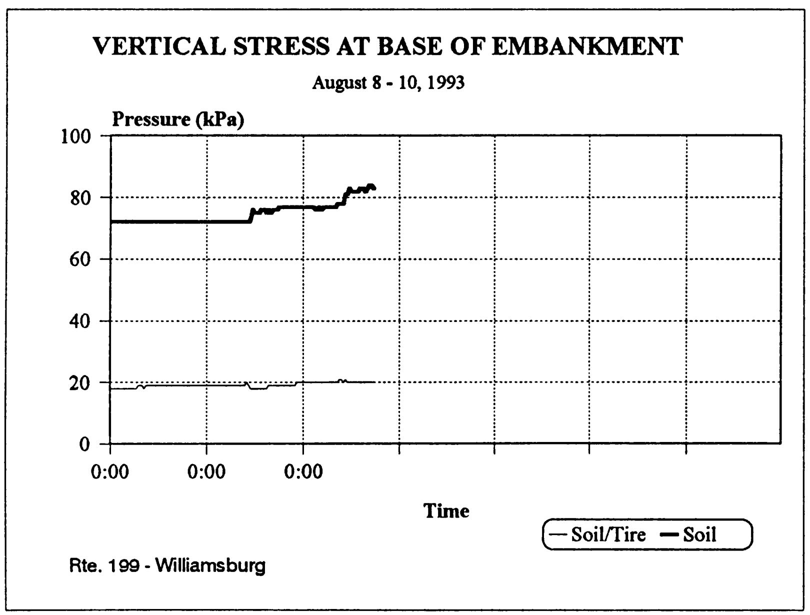

VERTICAL STRESS AT BASE OF EMBANKMENT
August 1 - 7, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

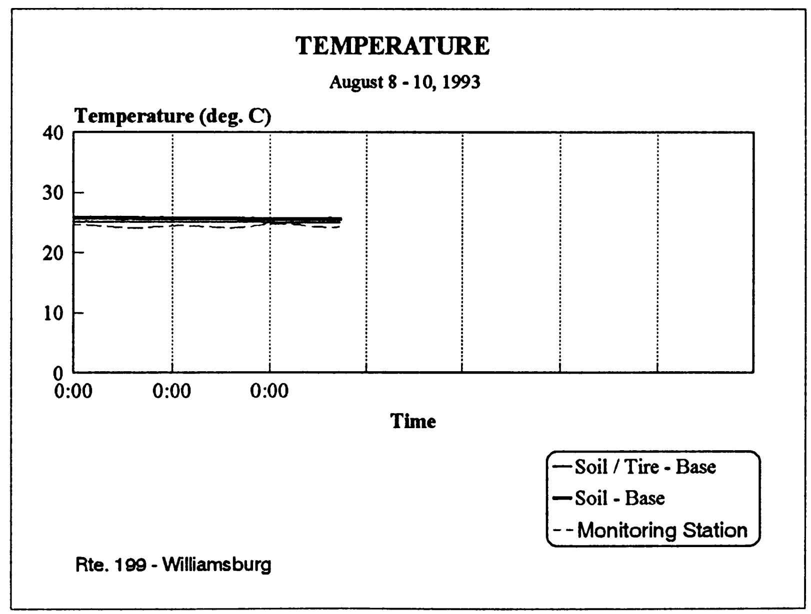

TEMPERATURE
August 1 - 7, 1993
Temperature (deg. C)
40
30
20
10
0
0:00 0:00 23:30 22:00 22:00 22:00 22:00 22:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

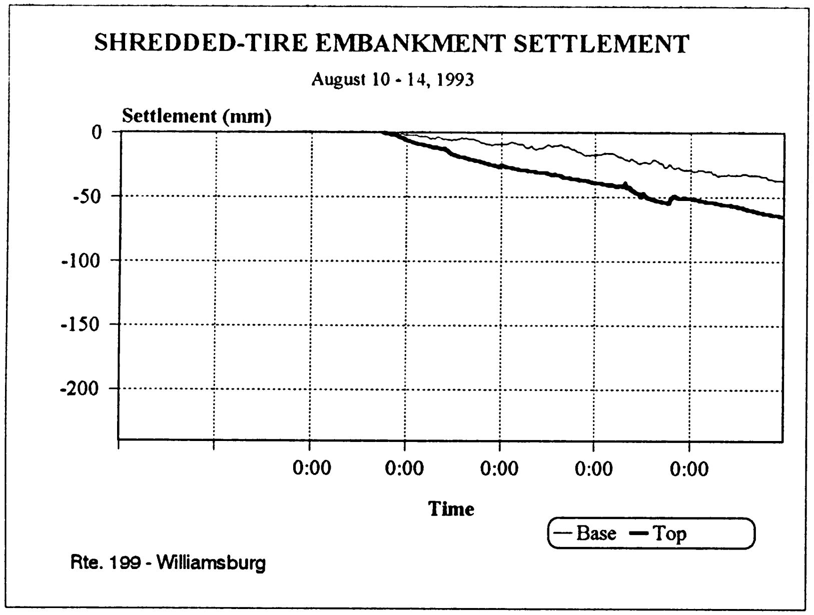


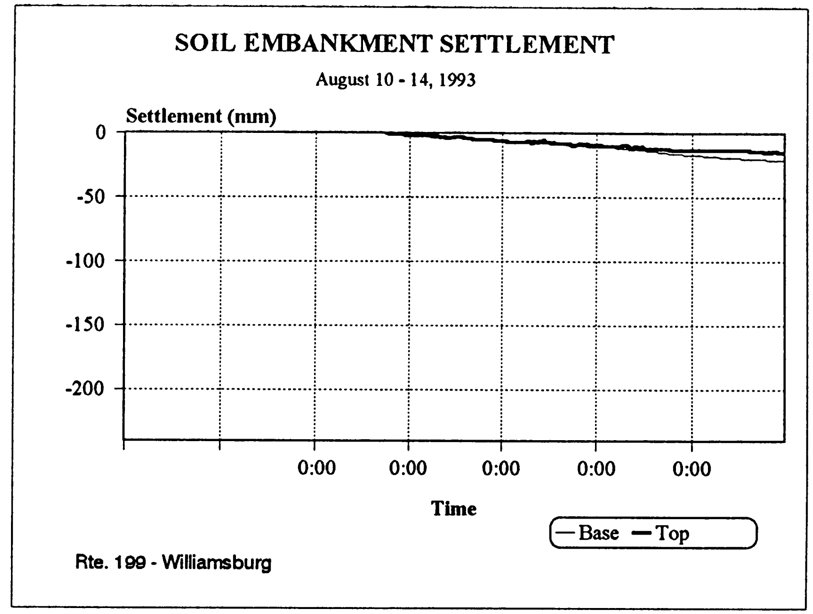


Note: Embankment completed on 8/10/93.

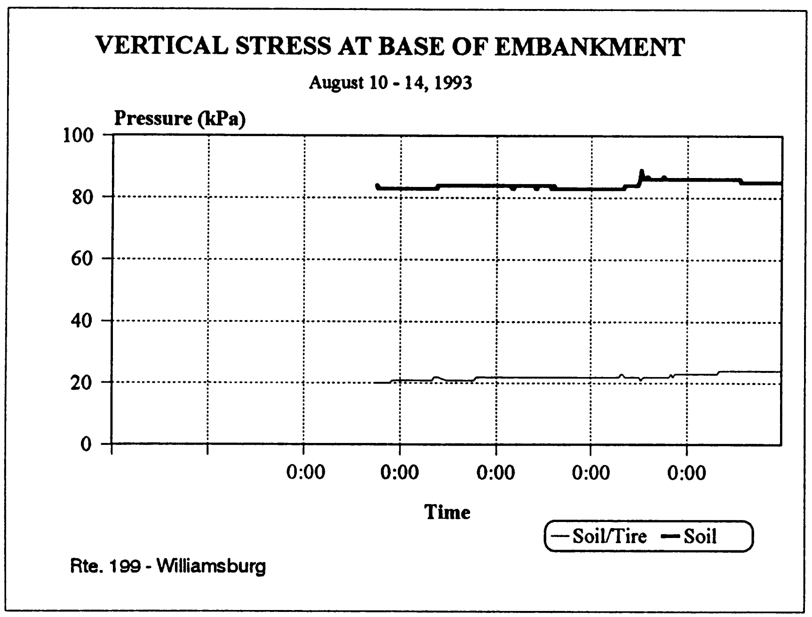


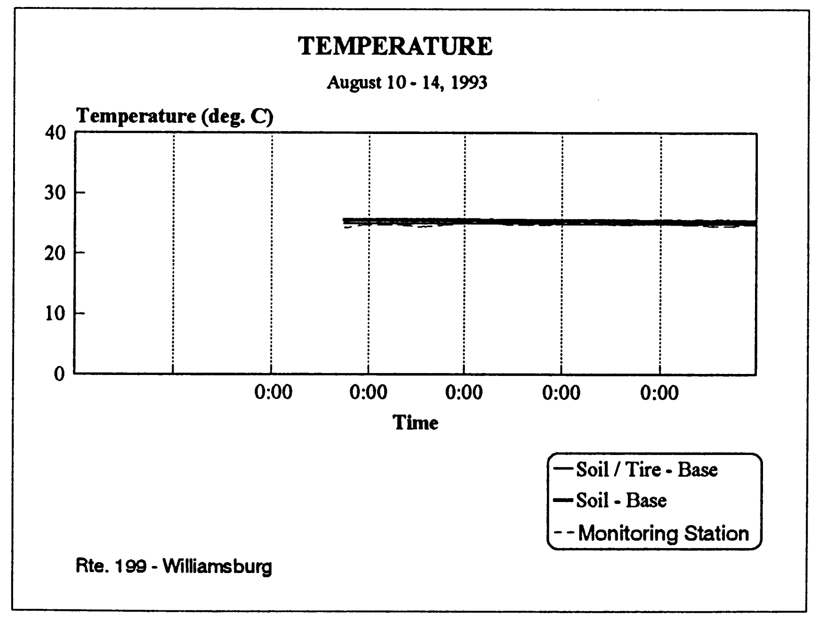


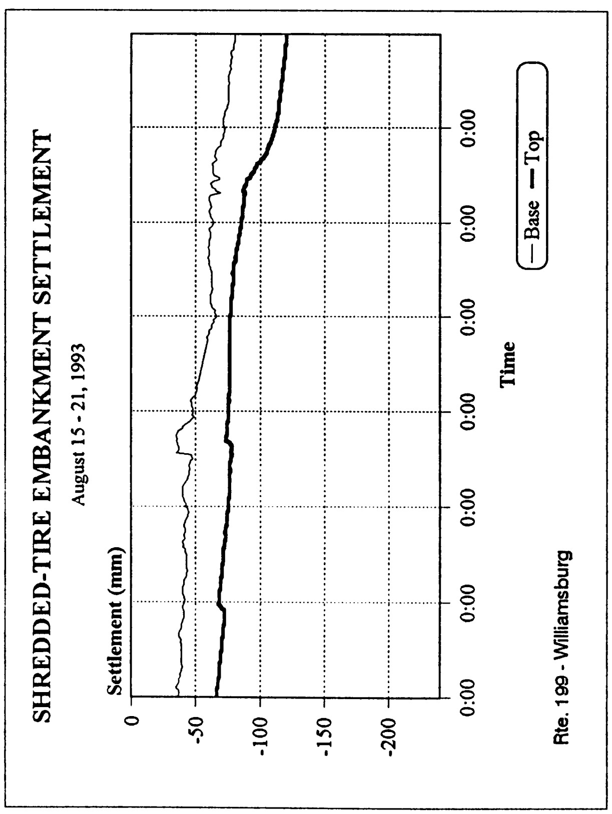


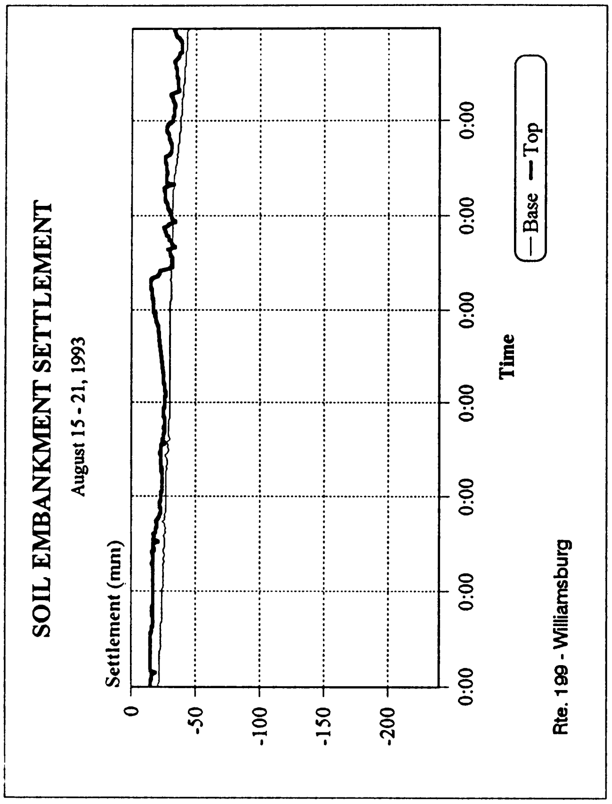


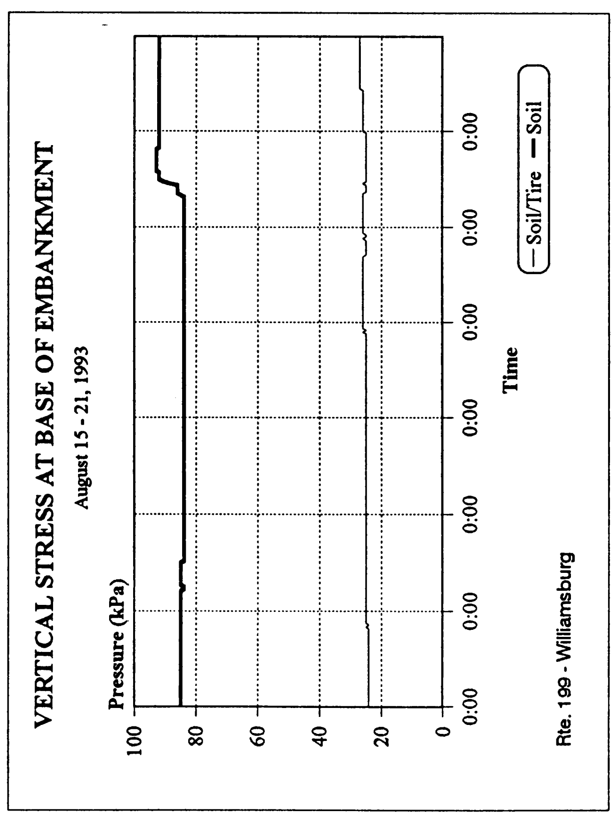
Note: Settlement as of 8/10/93. Surcharge placement began on 8/13/93.

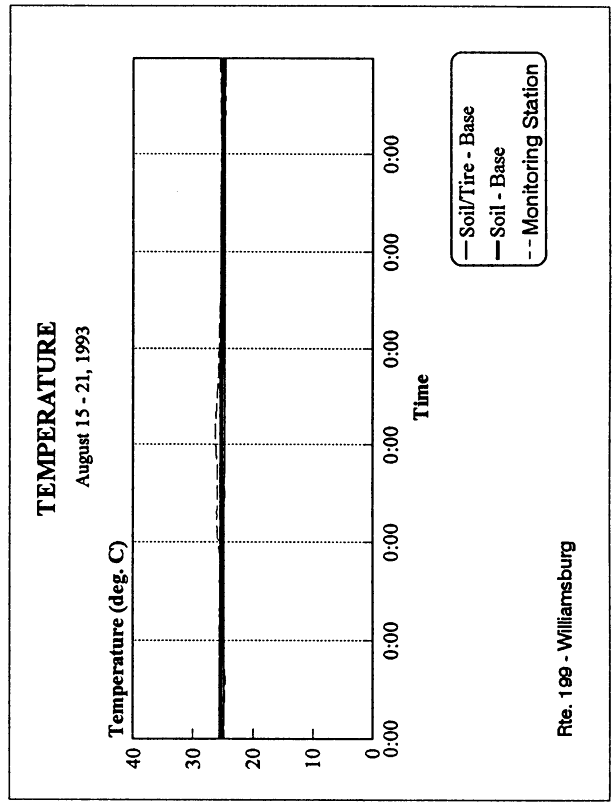


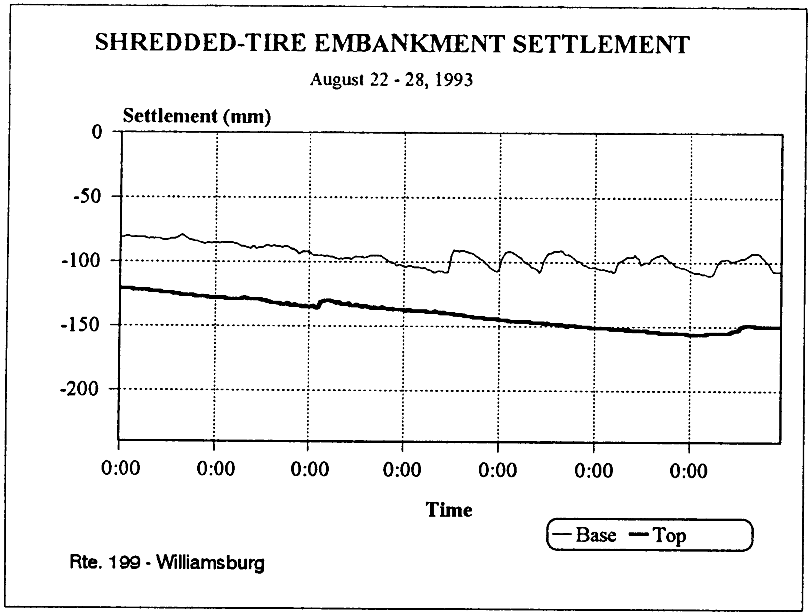


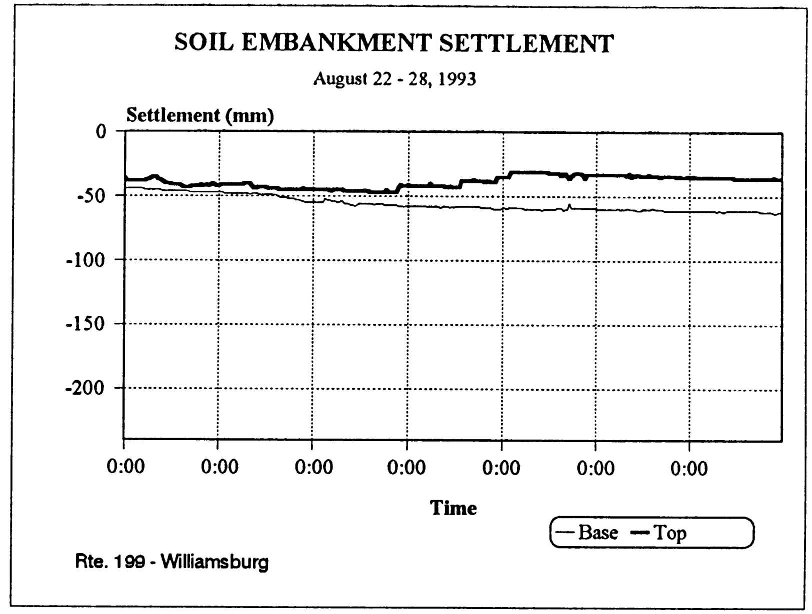

SHREDDED-TIRE EMBANKMENT SETTLEMENT
August 15 - 21, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg


SOIL EMBANKMENT SETTLEMENT
August 15 - 21, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

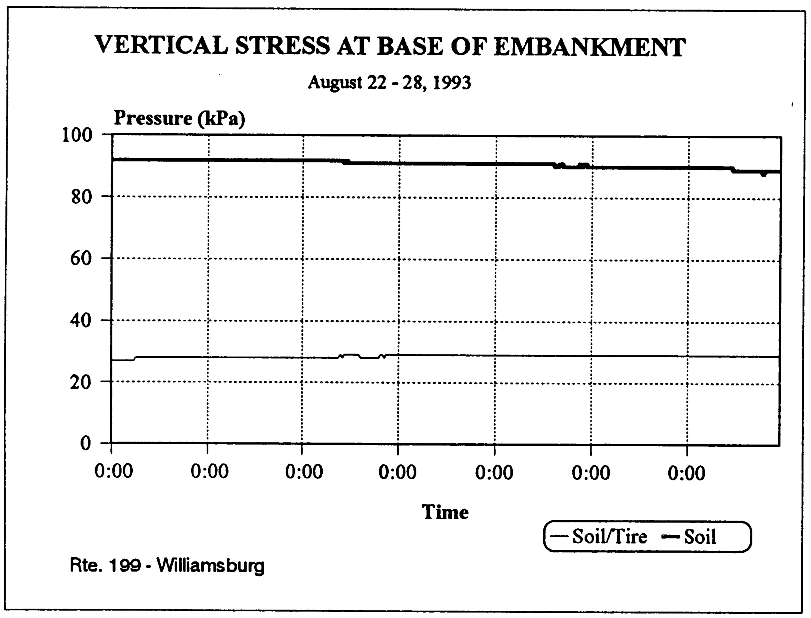

VERTICAL STRESS AT BASE OF EMBANKMENT
August 15 - 21, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

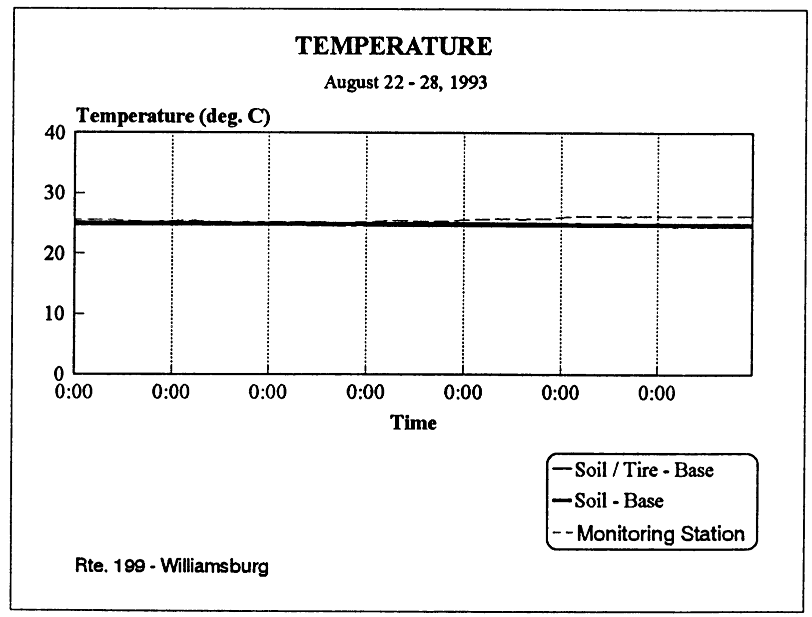

TEMPERATURE
August 15 - 21, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

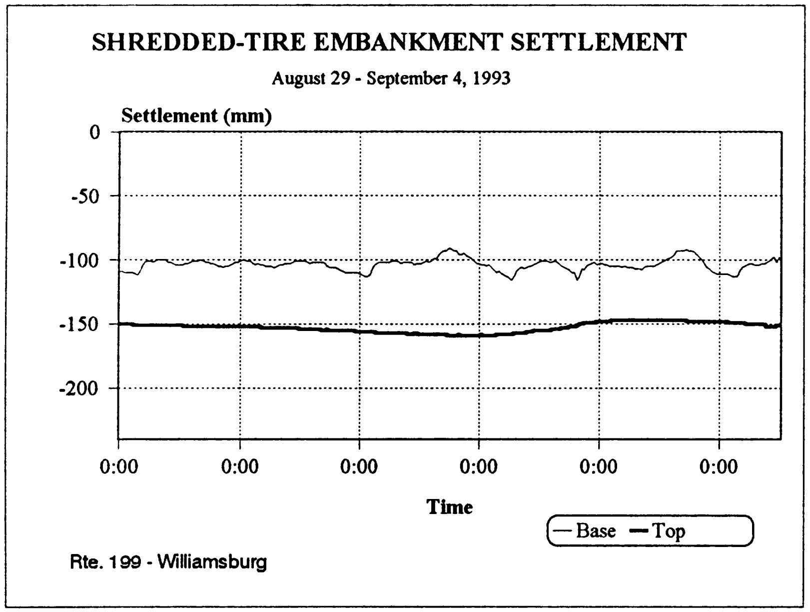


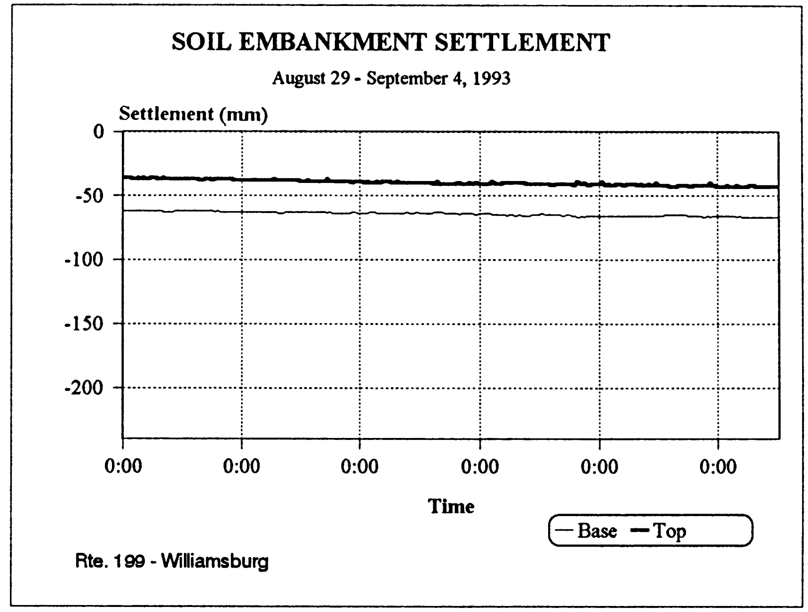


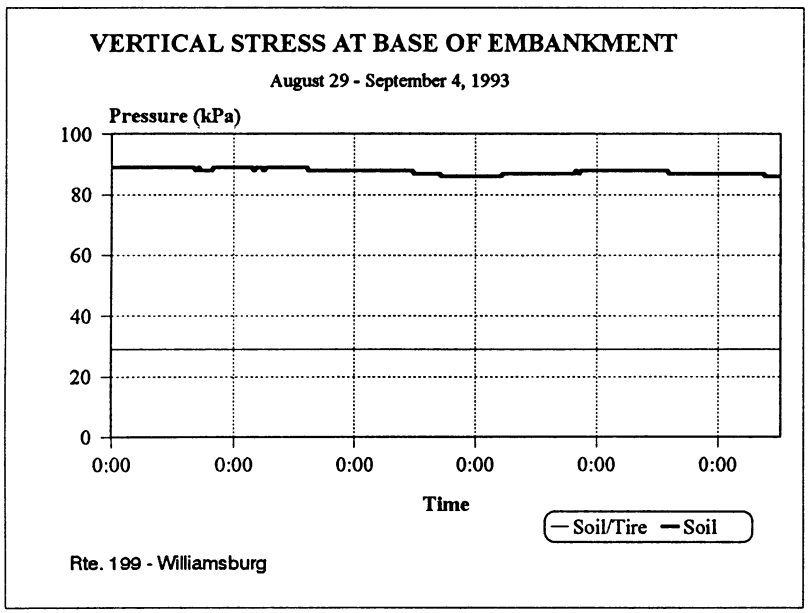
Note: Surcharge placement ended on 8/23/93.

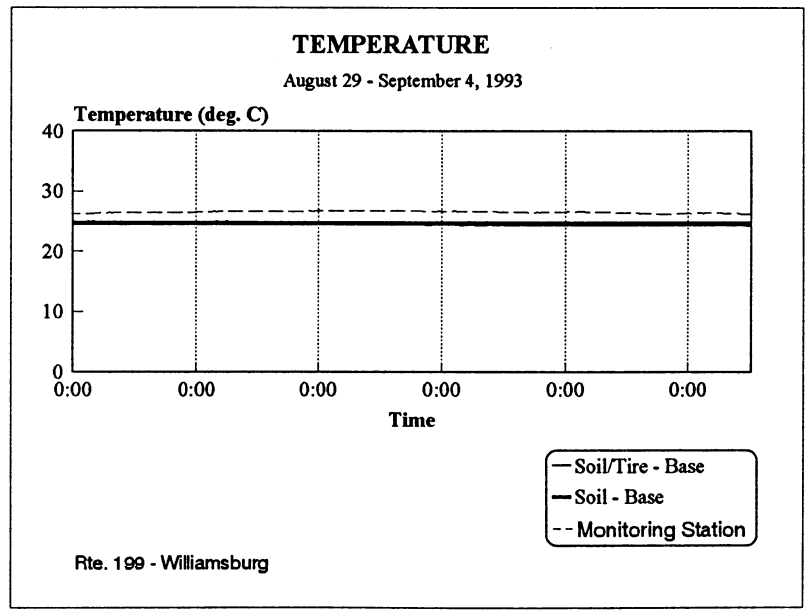


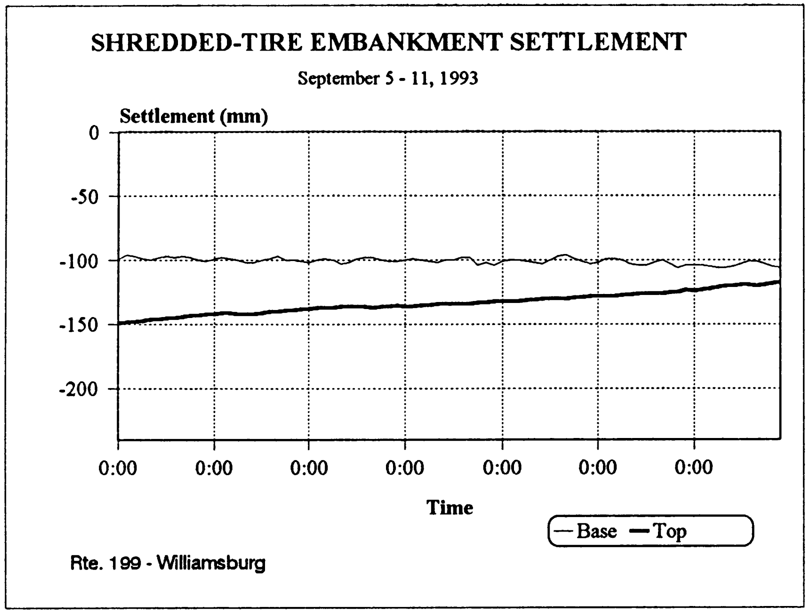


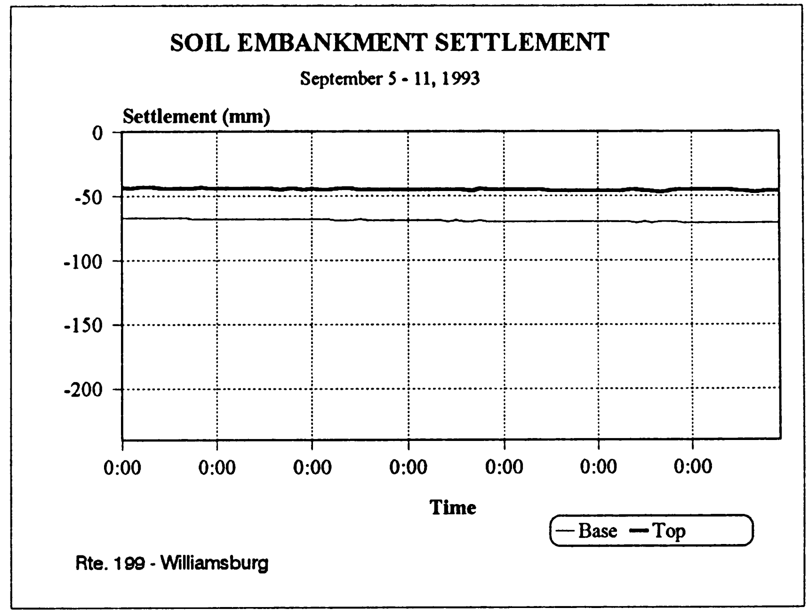

SHREDDED-TIRE EMBANKMENT SETTLEMENT
August 29 - September 4, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

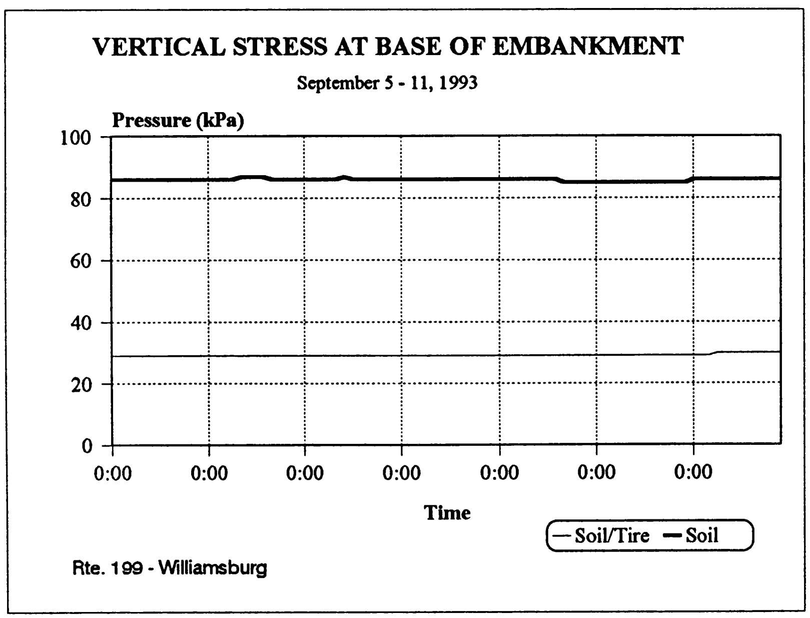

SOIL EMBANKMENT SETTLEMENT
August 29 - September 4, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

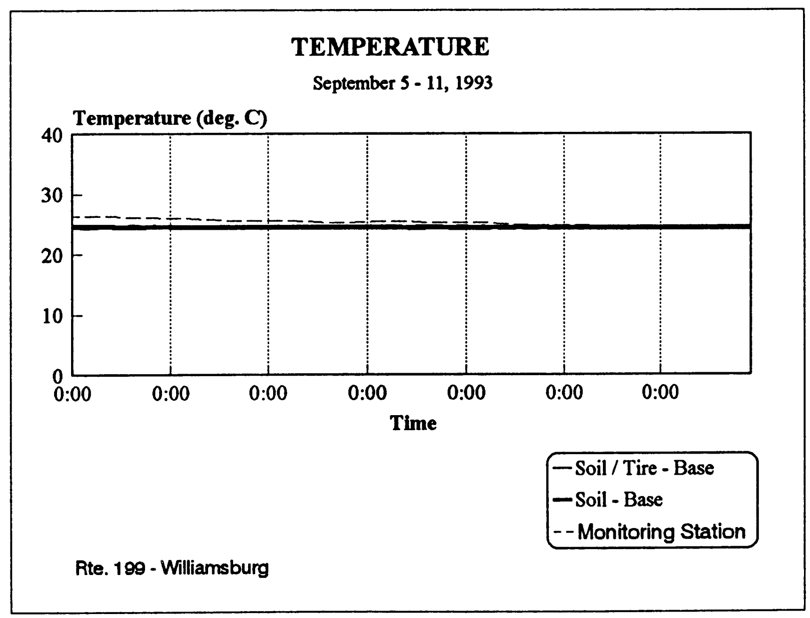

VERTICAL STRESS AT BASE OF EMBANKMENT
August 29 - September 4, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

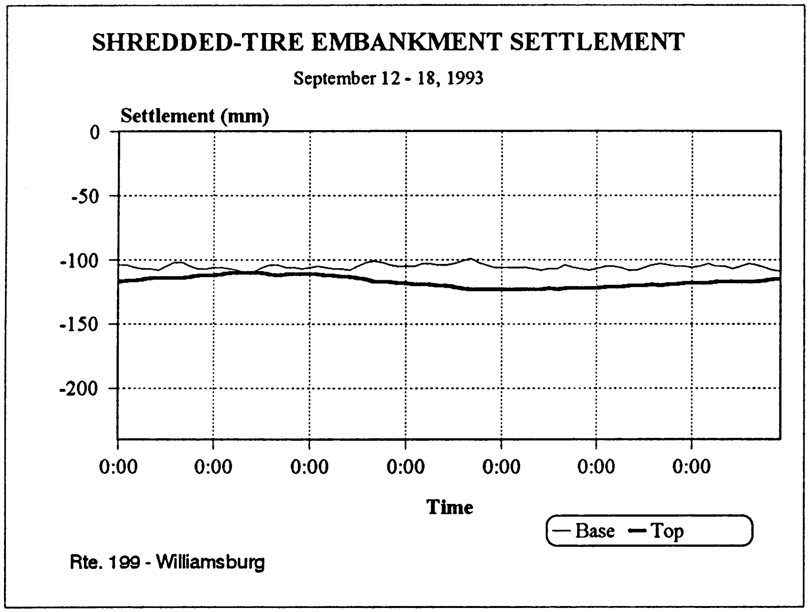

TEMPERATURE
August 29 - September 4, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

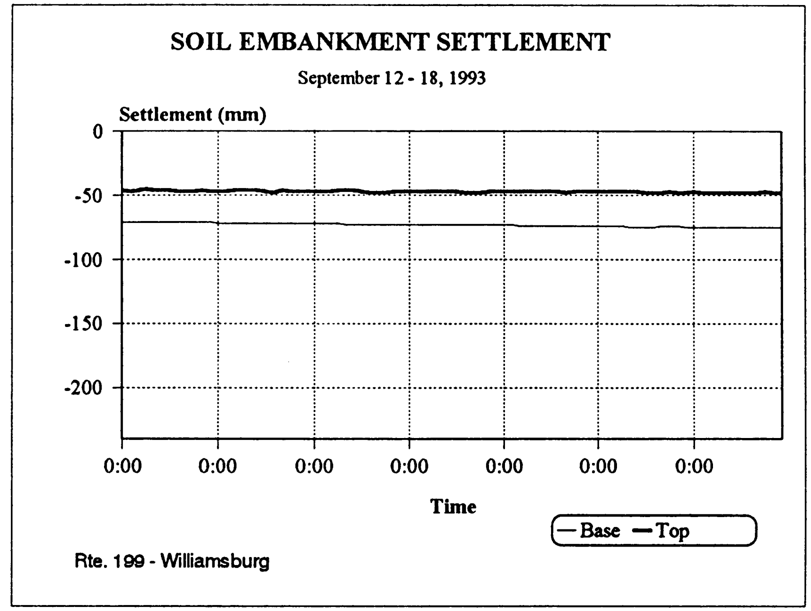

SHREDDED-TIRE EMBANKMENT SETTLEMENT
September 5 - 11, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

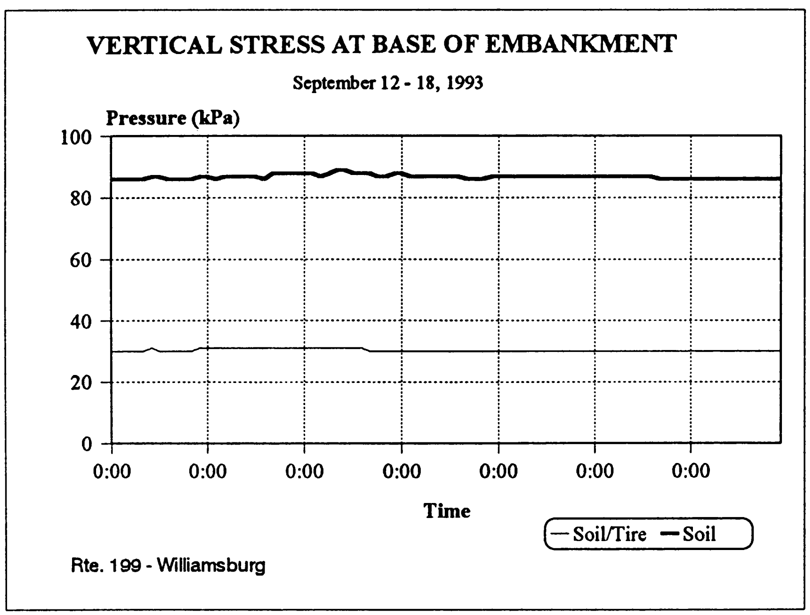

SOIL EMBANKMENT SETTLEMENT
September 5 - 11, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

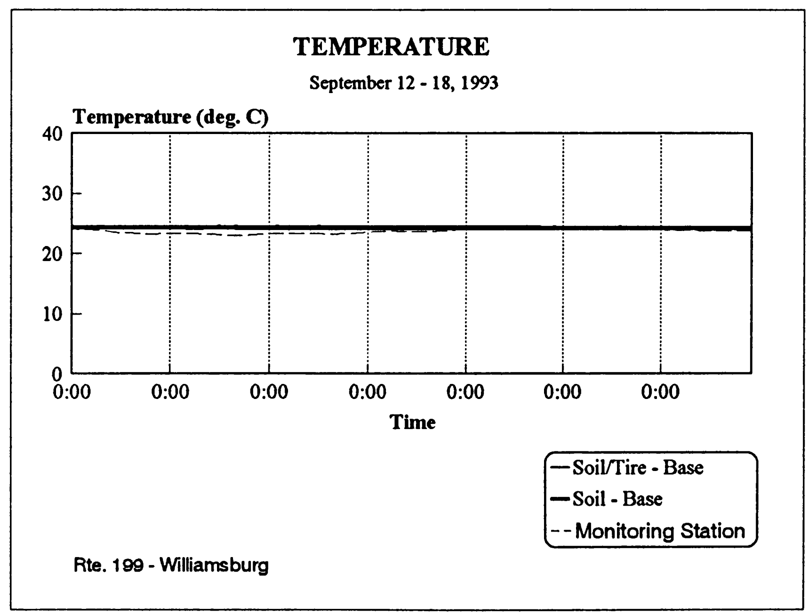

VERTICAL STRESS AT BASE OF EMBANKMENT
September 5 - 11, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

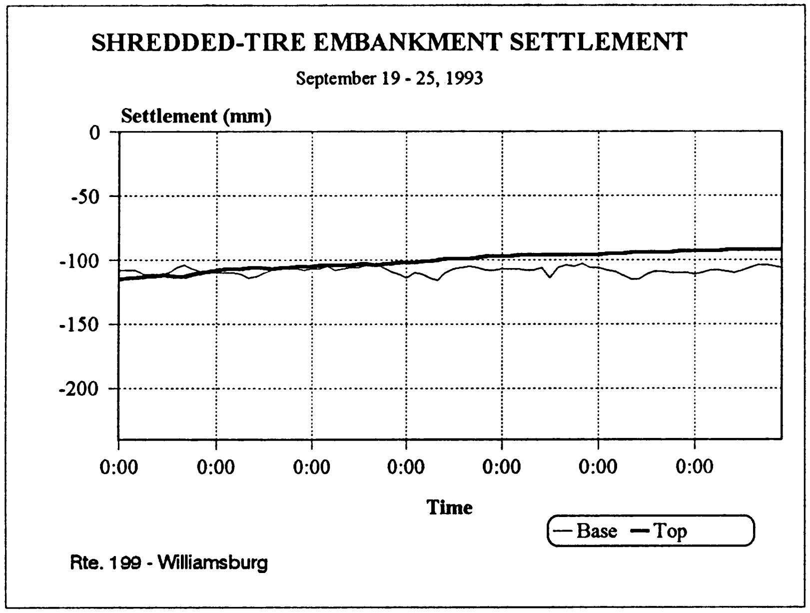

TEMPERATURE
September 5 - 11, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

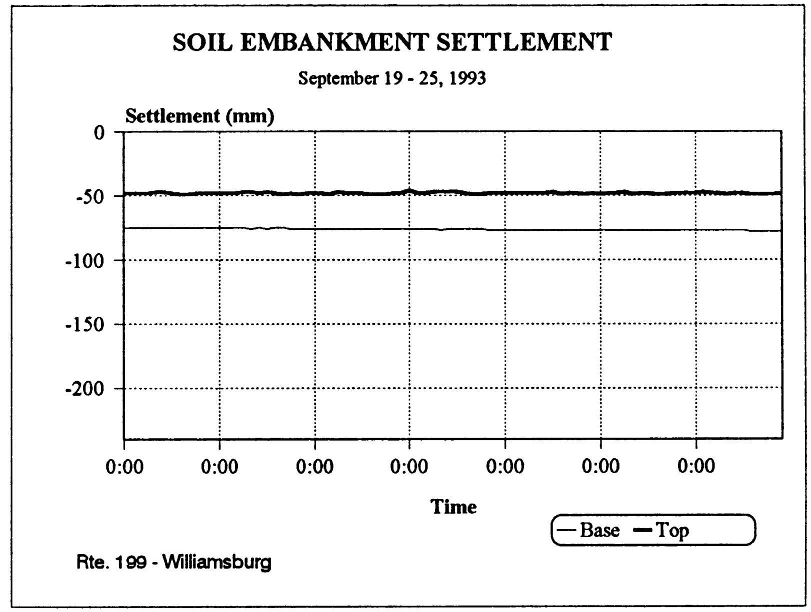

SHREDDED-TIRE EMBANKMENT SETTLEMENT
September 12 - 18, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

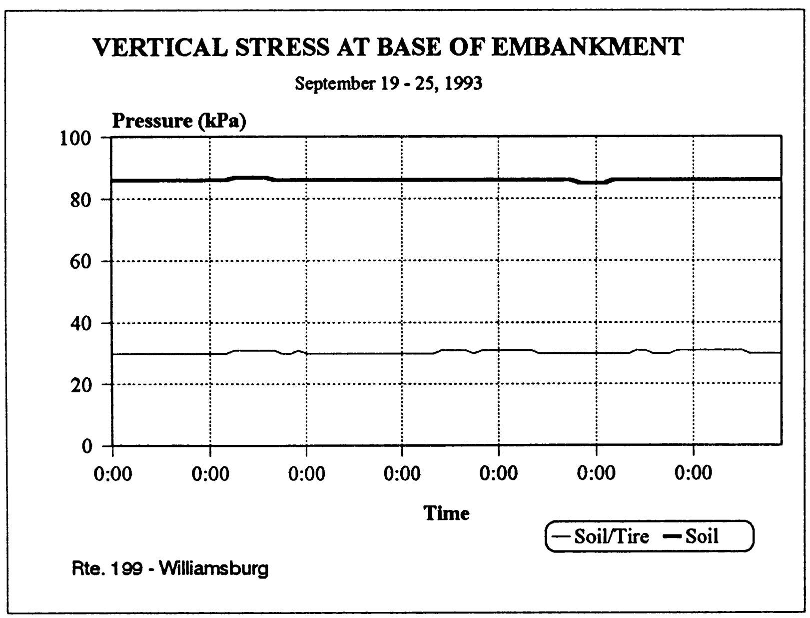

SOIL EMBANKMENT SETTLEMENT
September 12 - 18, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

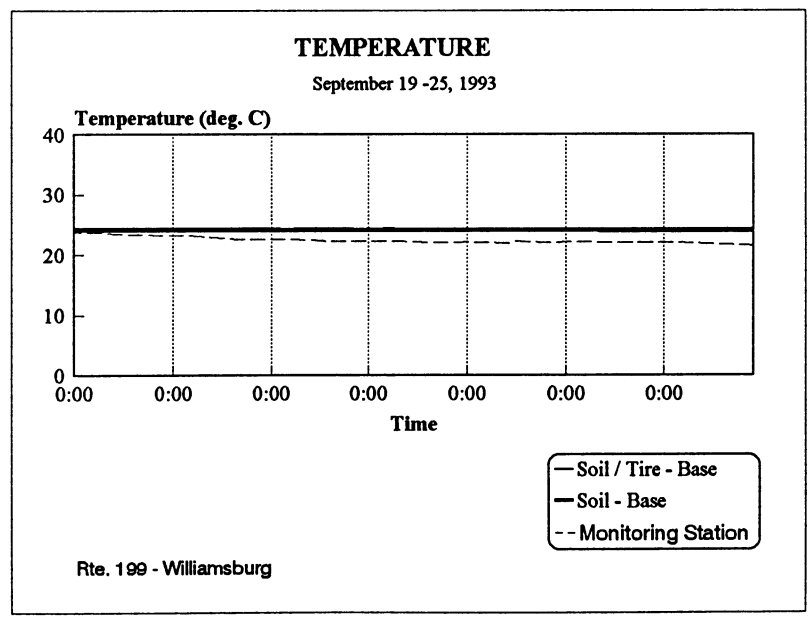

VERTICAL STRESS AT BASE OF EMBANKMENT
September 12 - 18, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

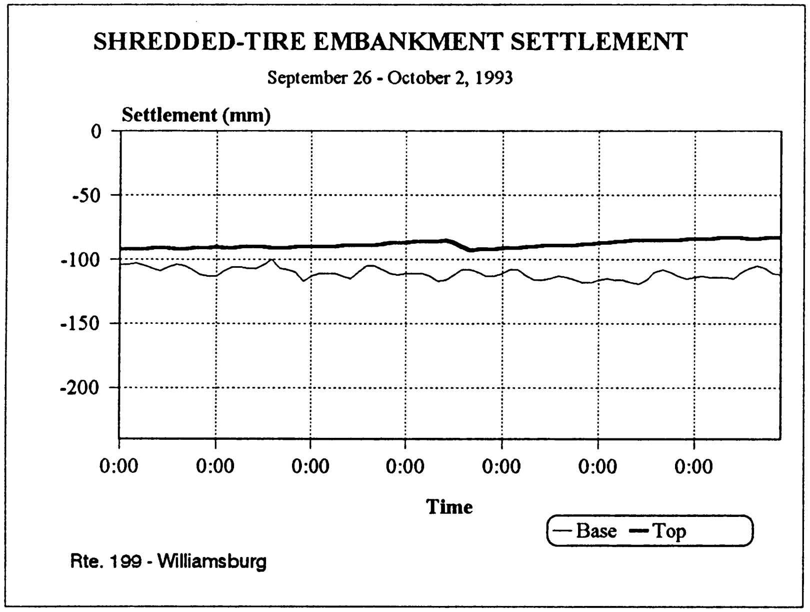

TEMPERATURE
September 12 - 18, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

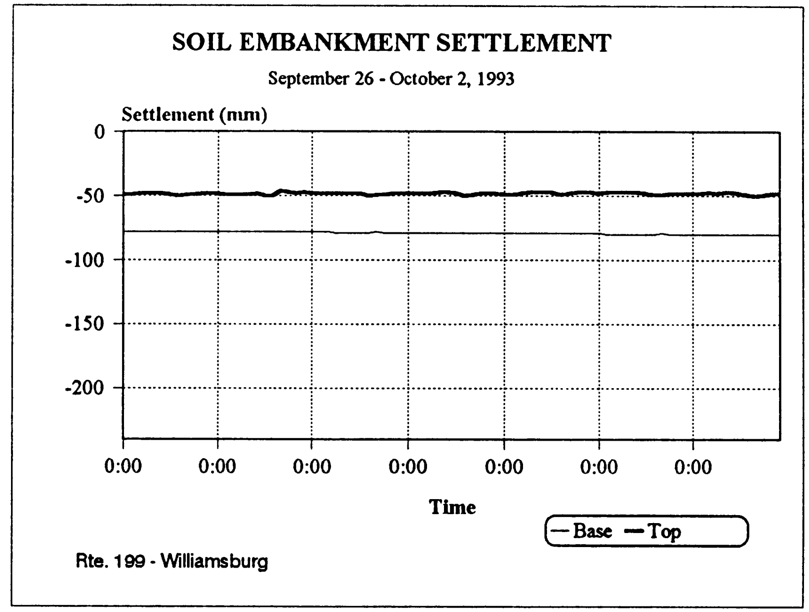

SHREDDED-TIRE EMBANKMENT SETTLEMENT
September 19 - 25, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Base
Top
Rte. 199 - Williamsburg

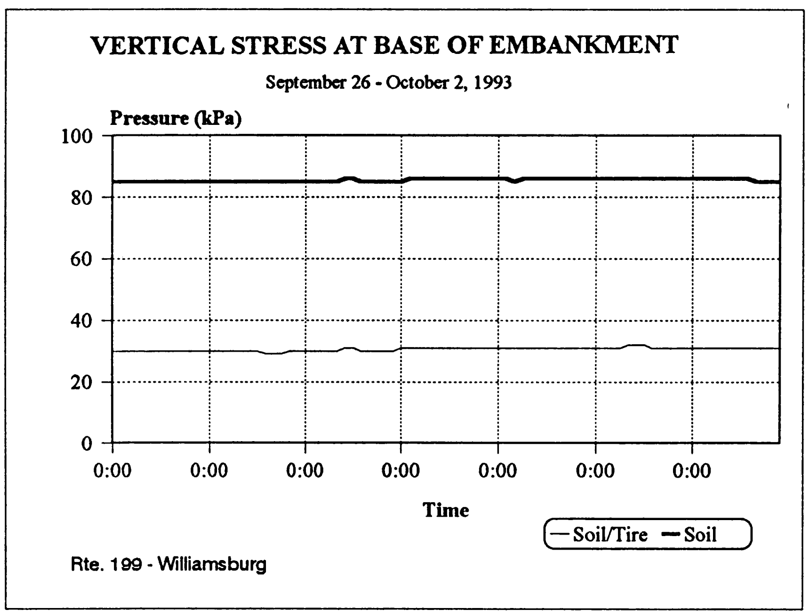

SOIL EMBANKMENT SETTLEMENT
September 19 - 25, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Base
Top
Rte. 199 - Williamsburg

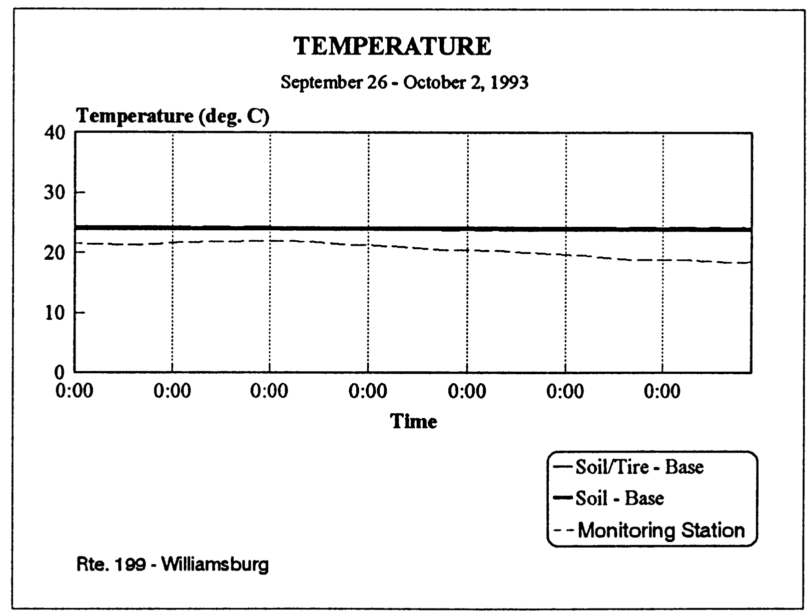

VERTICAL STRESS AT BASE OF EMBANKMENT
September 19 - 25, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

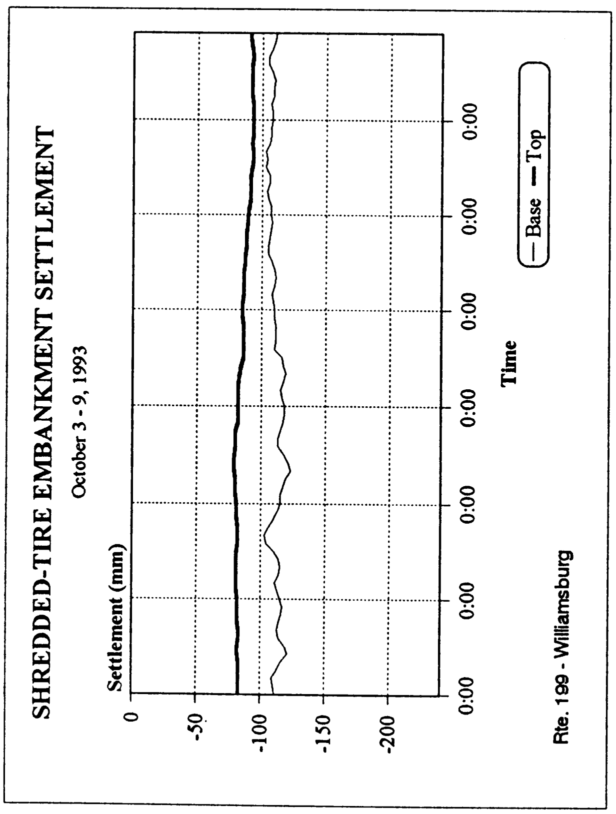

TEMPERATURE
September 19 -25, 1993
Temperature (deg. C)
40
30
20
10
0
0:00 0:00 0:00 0:00 0:00 0:00 0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg


SHREDDED-TIRE EMBANKMENT SETTLEMENT
September 26 - October 2, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

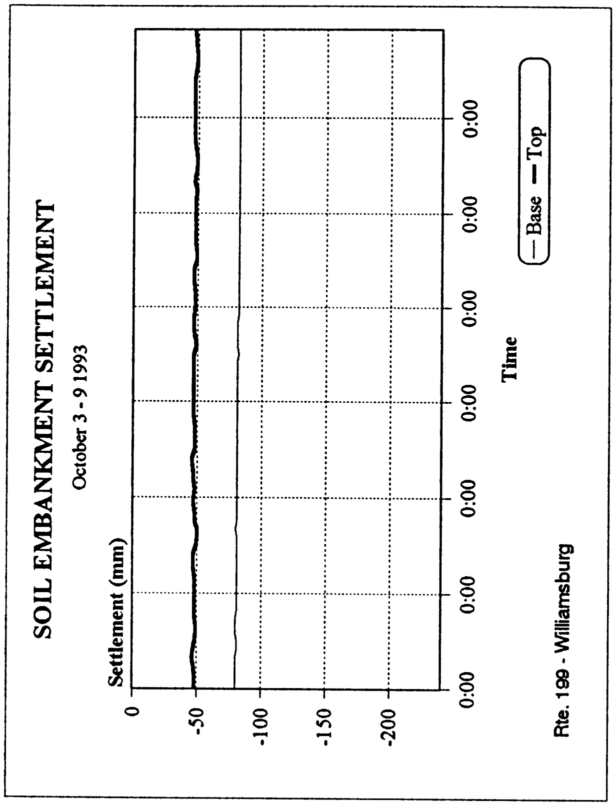

SOIL EMBANKMENT SETTLEMENT
September 26 - October 2, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg


VERTICAL STRESS AT BASE OF EMBANKMENT
September 26 - October 2, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

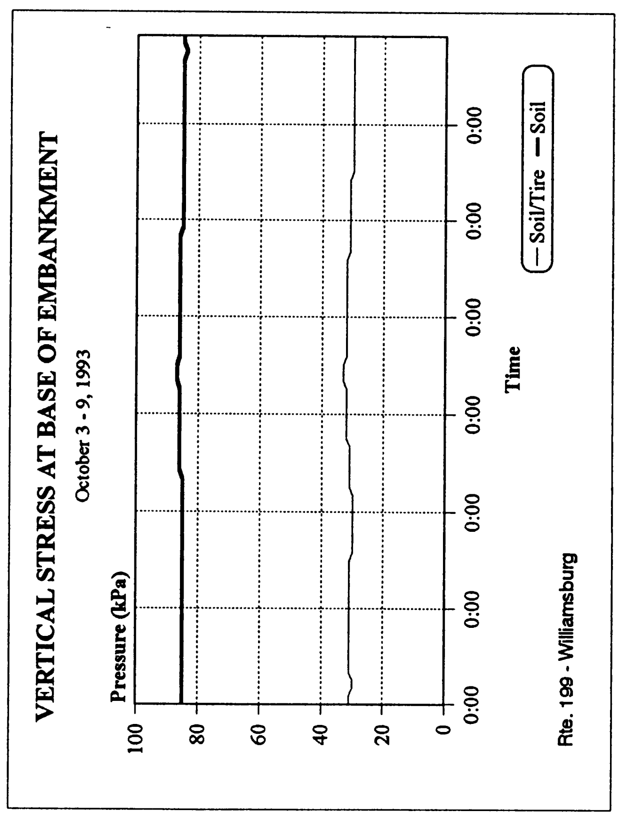

TEMPERATURE
September 26 - October 2, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg



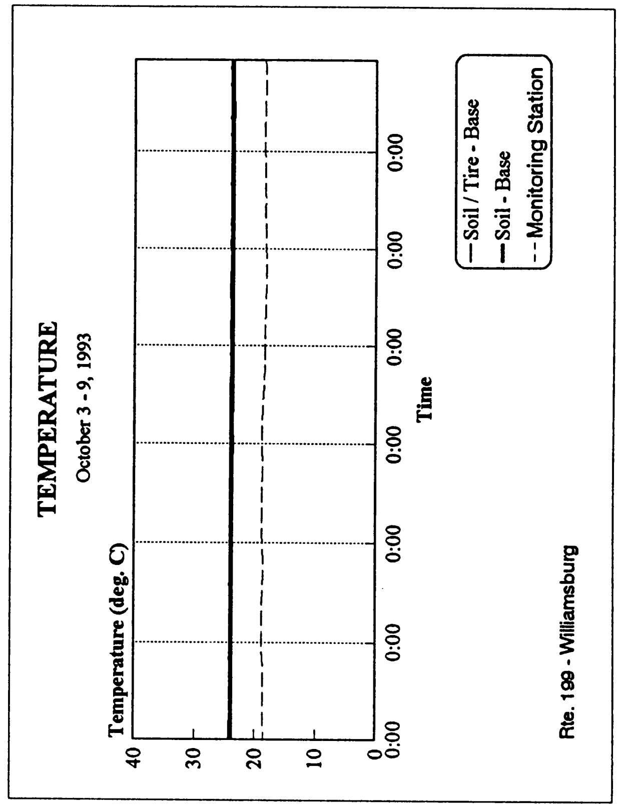
SHREDDED-TIRE EMBANKMENT SETTLEMENT
October 3 - 9, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
— Base — Top
Rte. 199 - Williamsburg



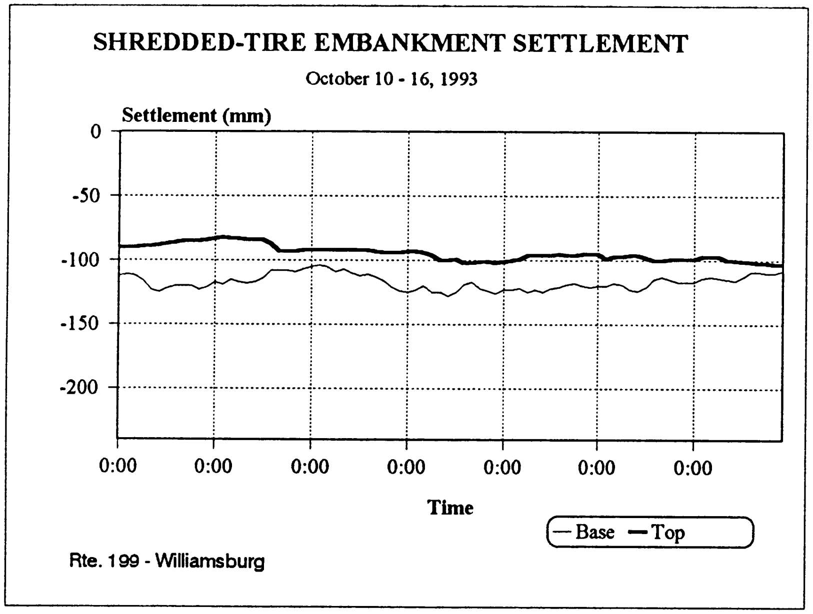
SOIL EMBANKMENT SETTLEMENT
October 3 - 9 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
— Base — Top
Rte. 199 - Williamsburg

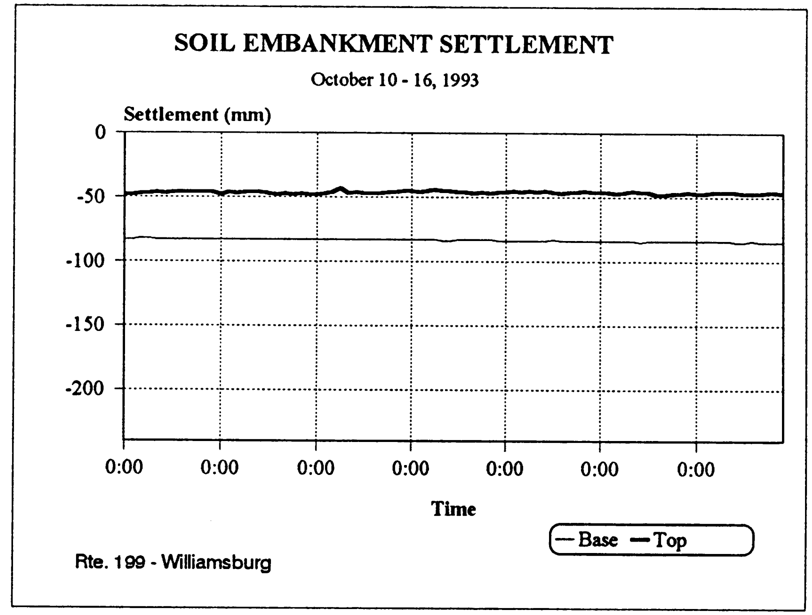


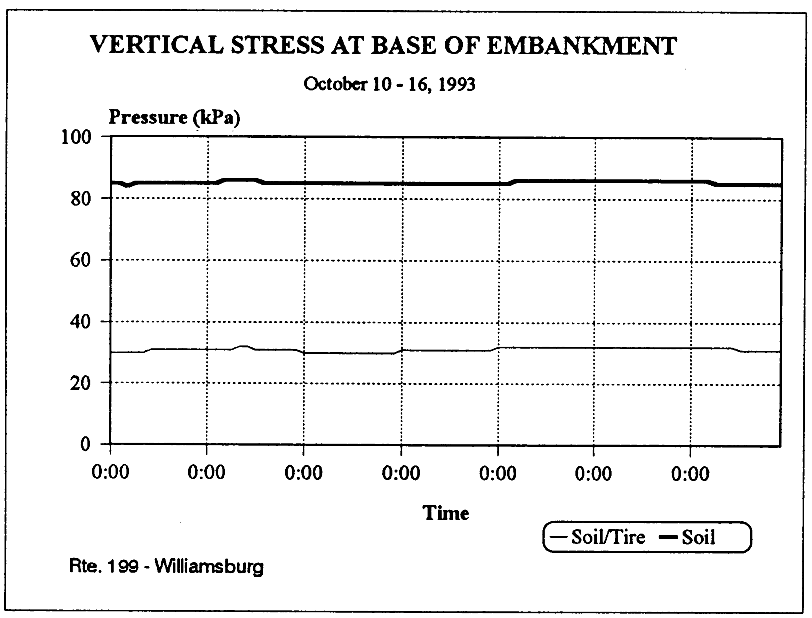
VERTICAL STRESS AT BASE OF EMBANKMENT
October 3 - 9, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
— Soil/Tire — Soil
Rte. 199 - Williamsburg

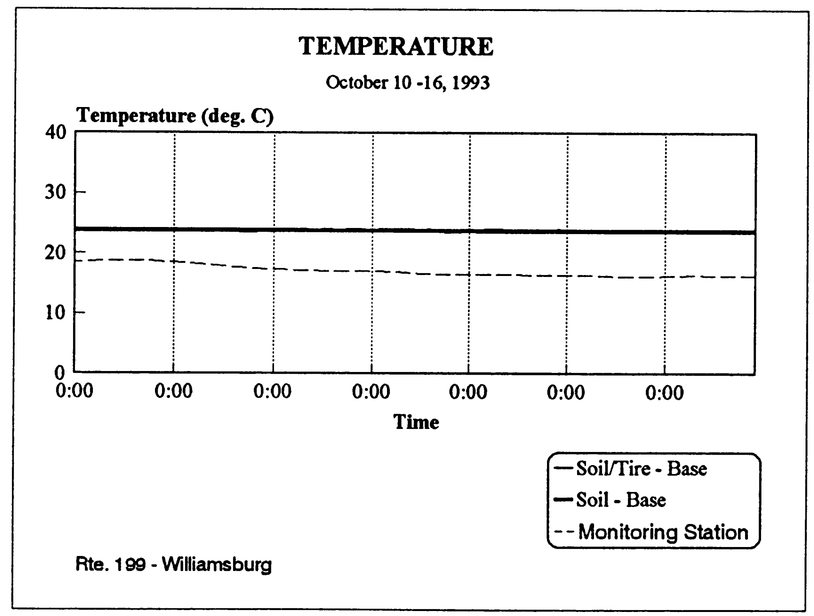


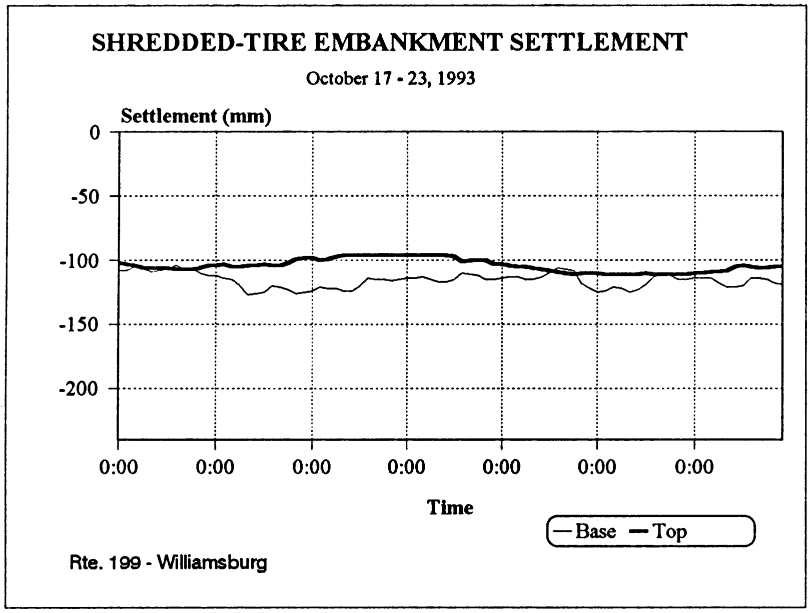
TEMPERATURE
October 3 - 9, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
— Soil / Tire - Base
— Soil - Base
- - Monitoring Station
Rte. 199 - Williamsburg

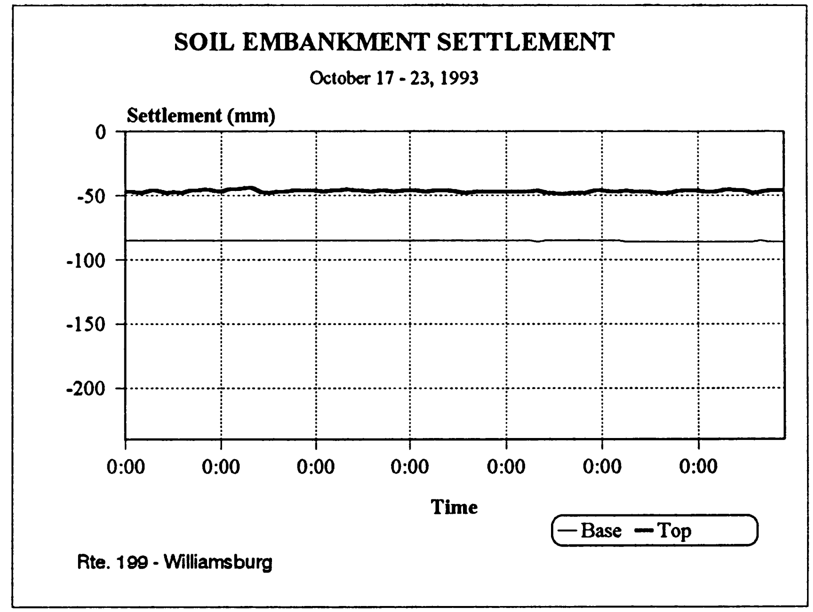

SHREDDED-TIRE EMBANKMENT SETTLEMENT
October 10 - 16, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

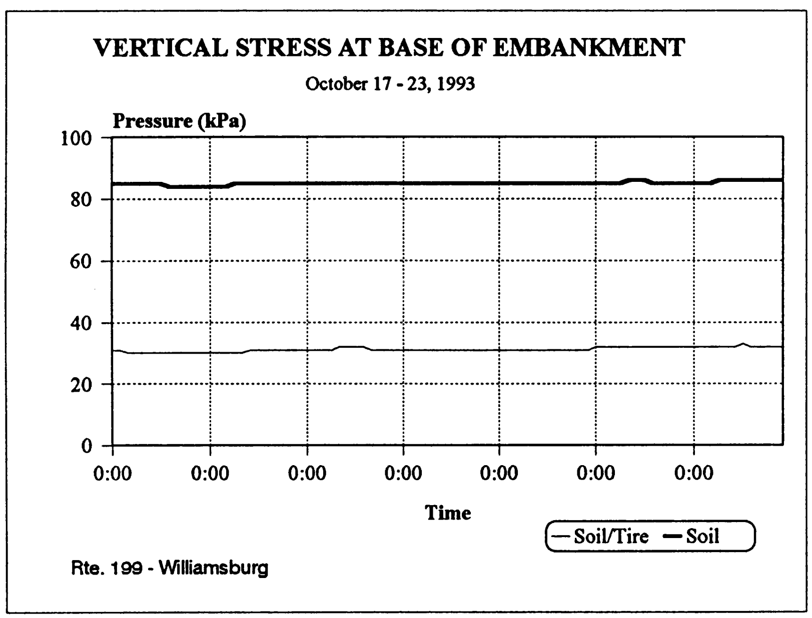

SOIL EMBANKMENT SETTLEMENT
October 10 - 16, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

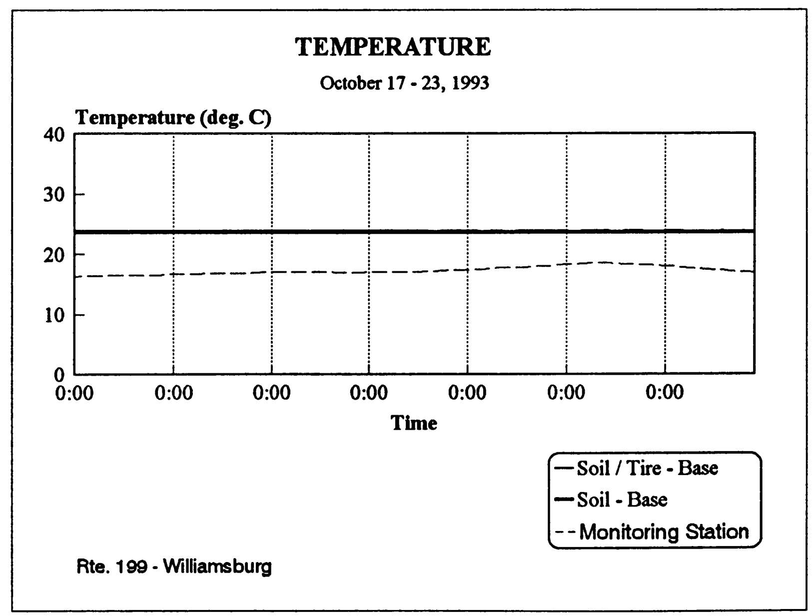

VERTICAL STRESS AT BASE OF EMBANKMENT
October 10 - 16, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

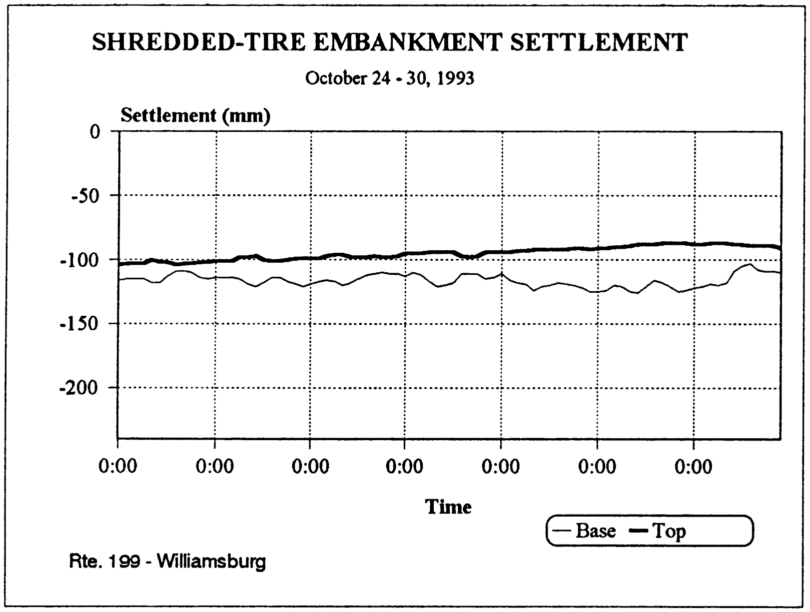

TEMPERATURE
October 10 -16, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

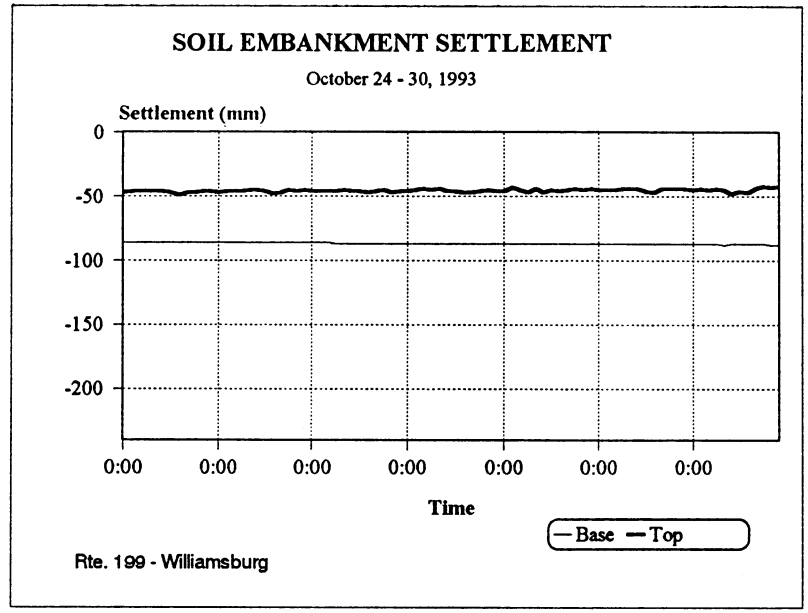

SHREDDED-TIRE EMBANKMENT SETTLEMENT
October 17 - 23, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

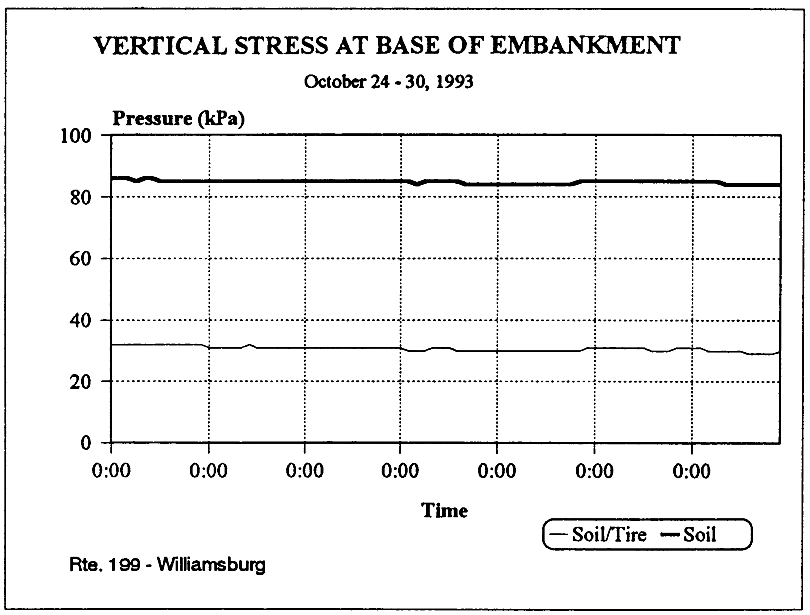

SOIL EMBANKMENT SETTLEMENT
October 17 - 23, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

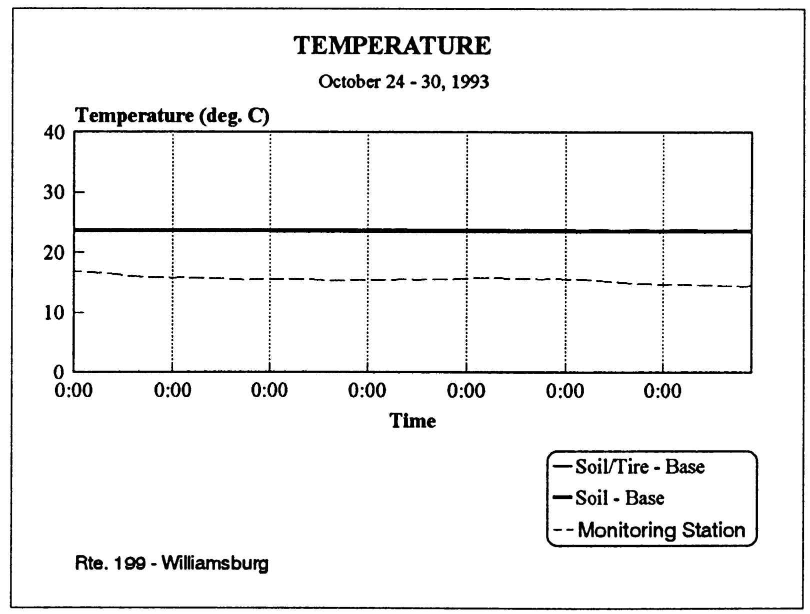

VERTICAL STRESS AT BASE OF EMBANKMENT
October 17 - 23, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

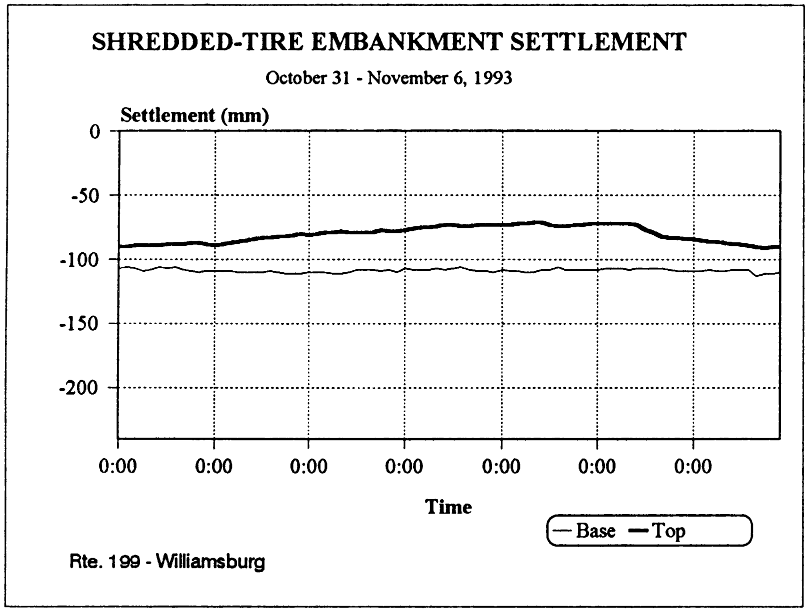

TEMPERATURE
October 17 - 23, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg


SHREDDED-TIRE EMBANKMENT SETTLEMENT
October 24 - 30, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg

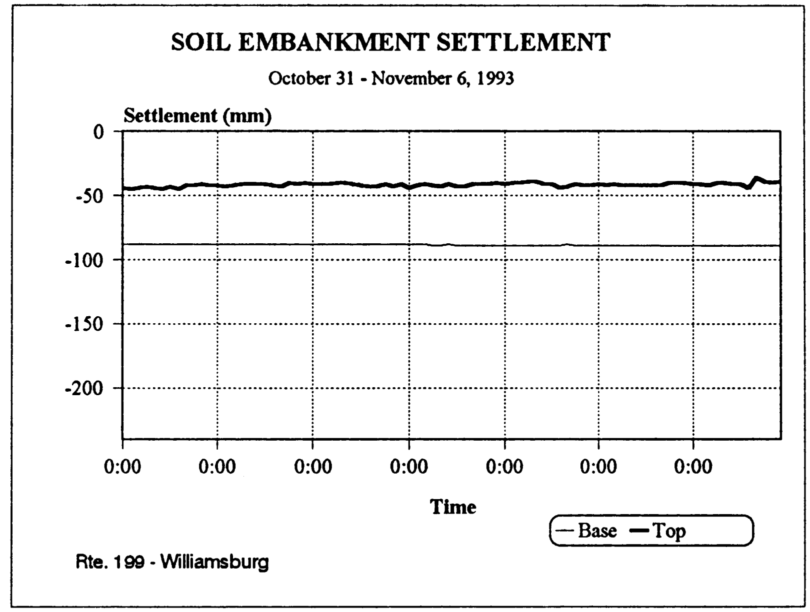

SOIL EMBANKMENT SETTLEMENT
October 24 - 30, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Base
Top
Rte. 199 - Williamsburg


VERTICAL STRESS AT BASE OF EMBANKMENT
October 24 - 30, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

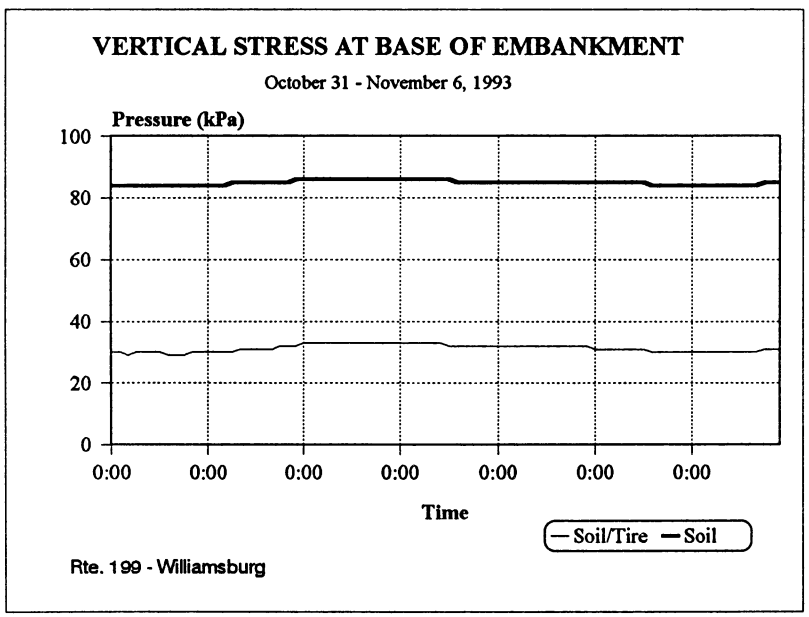

TEMPERATURE
October 24 - 30, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
0:00
0:00
0:00
0:00
0:00
0:00
Time
Soil/Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg



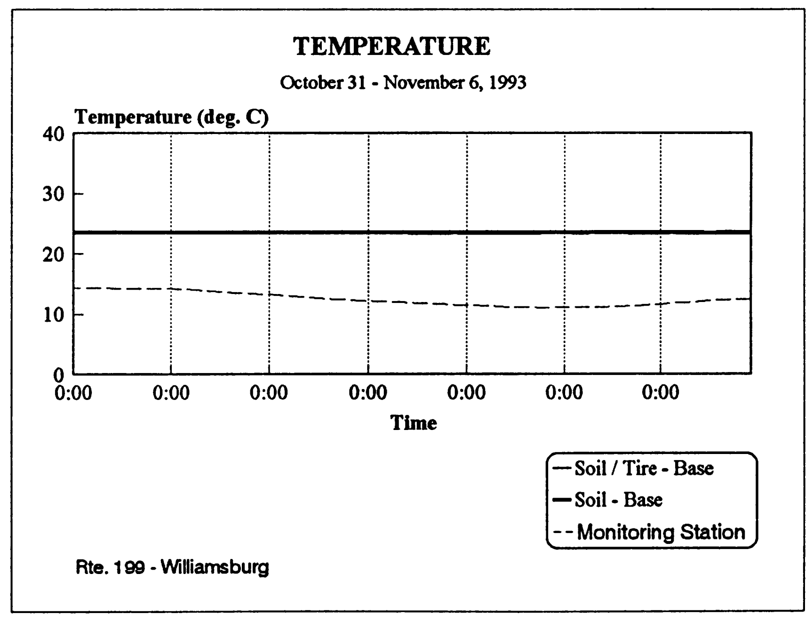
SHREDDED-TIRE EMBANKMENT SETTLEMENT
October 31 - November 6, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg



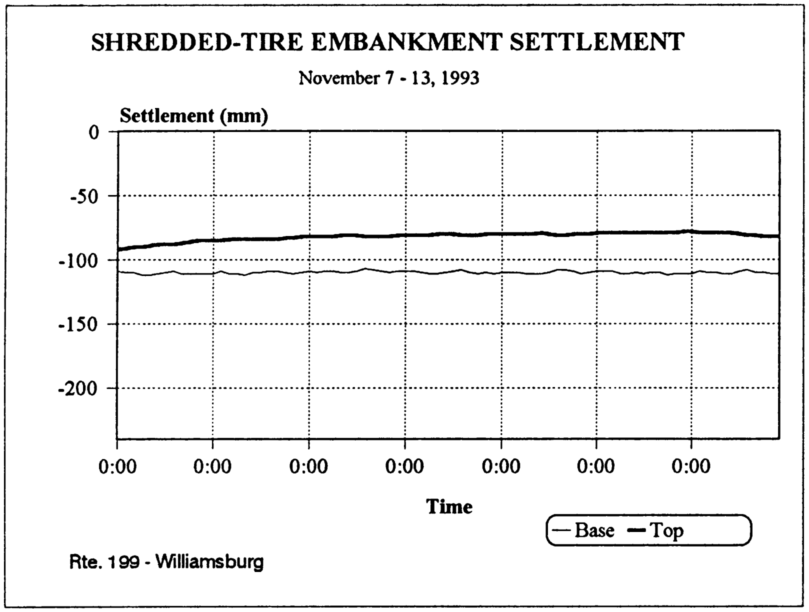
SOIL EMBANKMENT SETTLEMENT
October 31 - November 6, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg

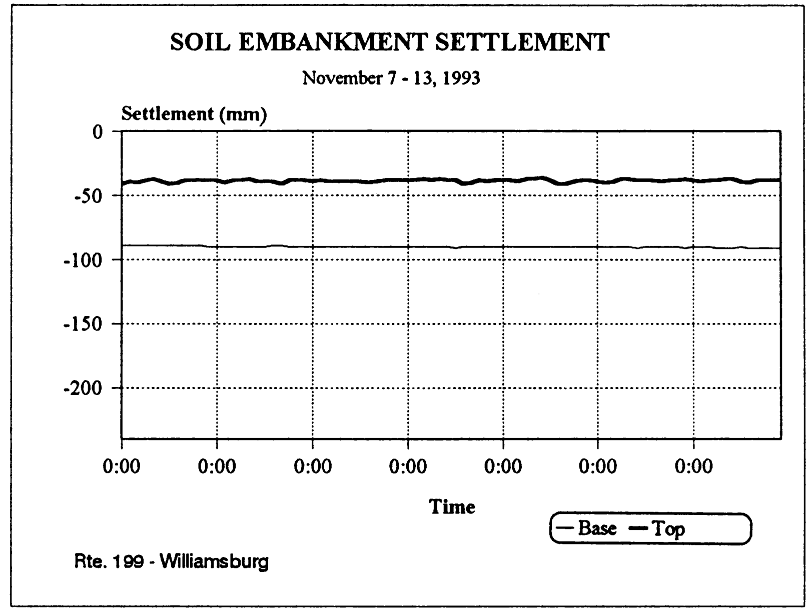


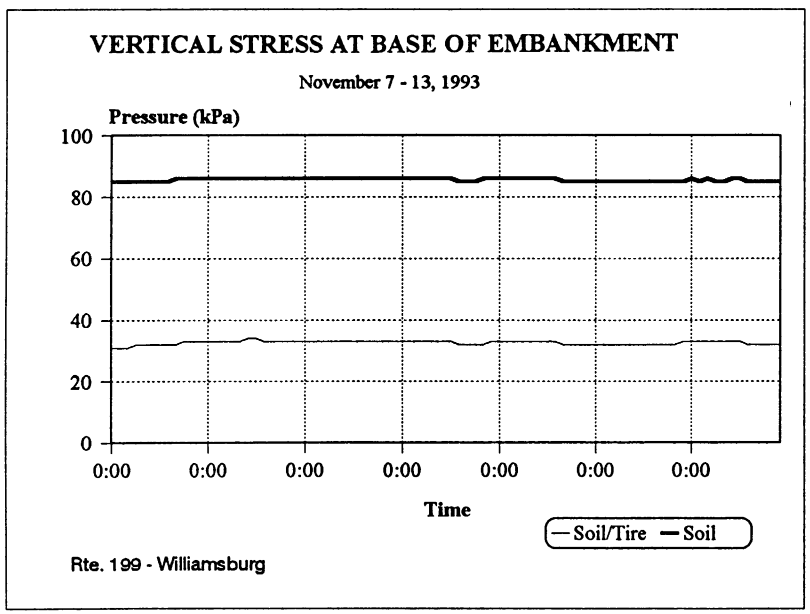
VERTICAL STRESS AT BASE OF EMBANKMENT
October 31 - November 6, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg

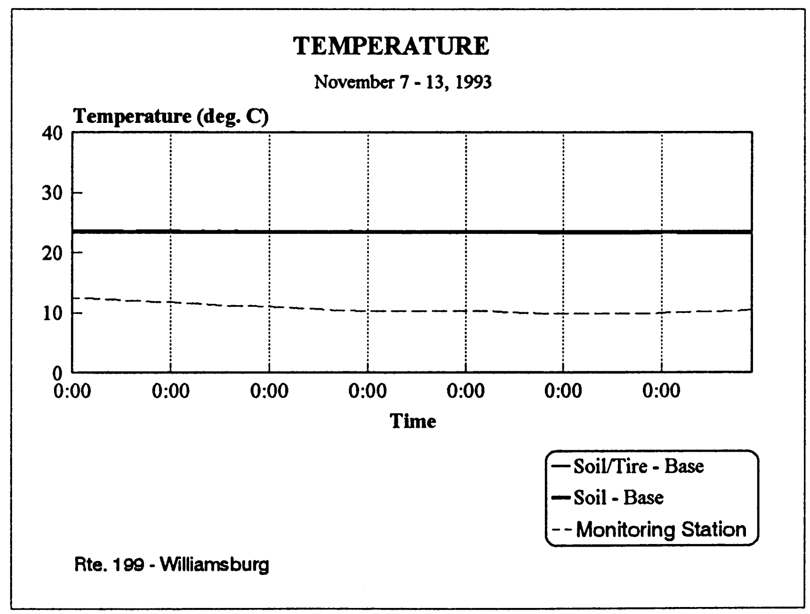


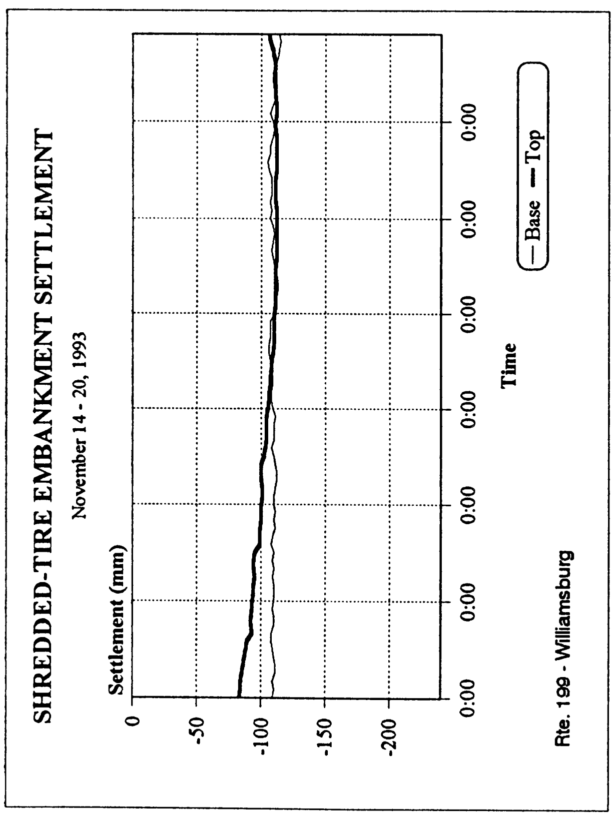
TEMPERATURE
October 31 - November 6, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg

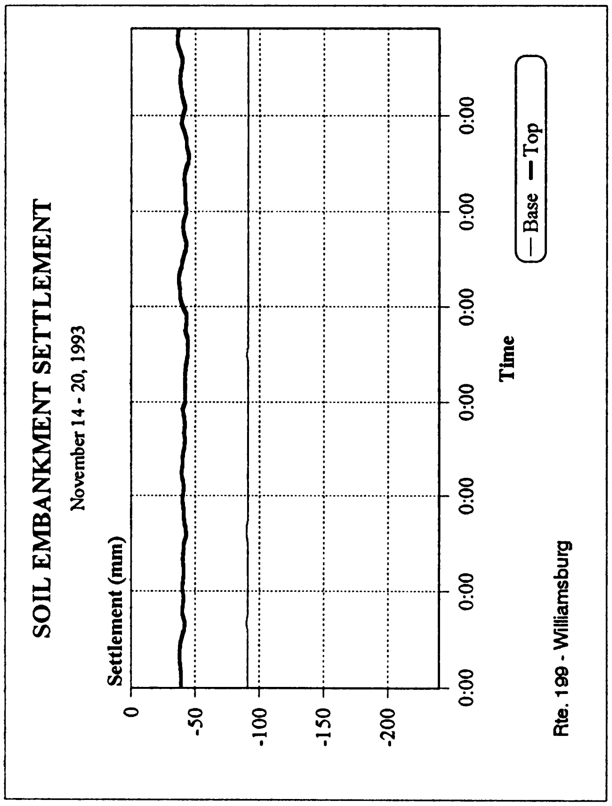

SHREDDED-TIRE EMBANKMENT SETTLEMENT
November 7 - 13, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
— Base — Top
Rte. 199 - Williamsburg

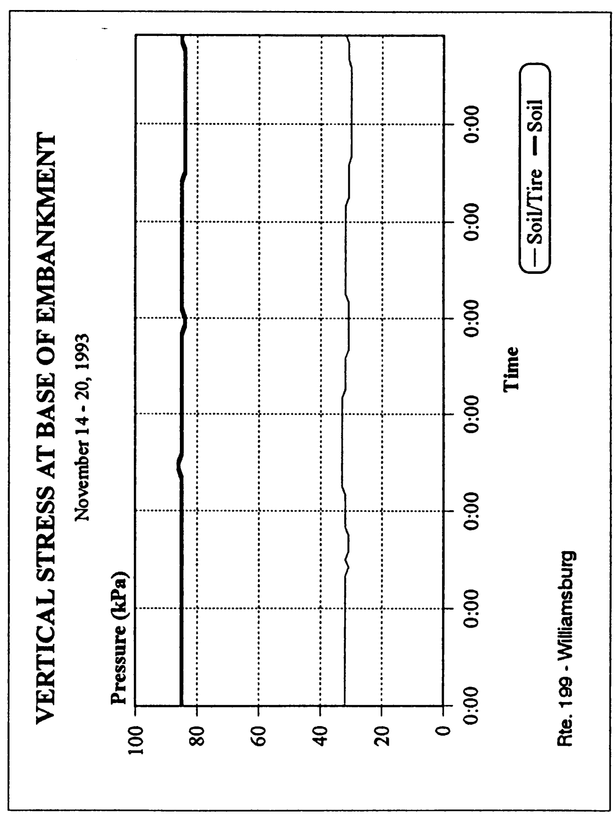

SOIL EMBANKMENT SETTLEMENT
November 7 - 13, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
— Base — Top
Rte. 199 - Williamsburg

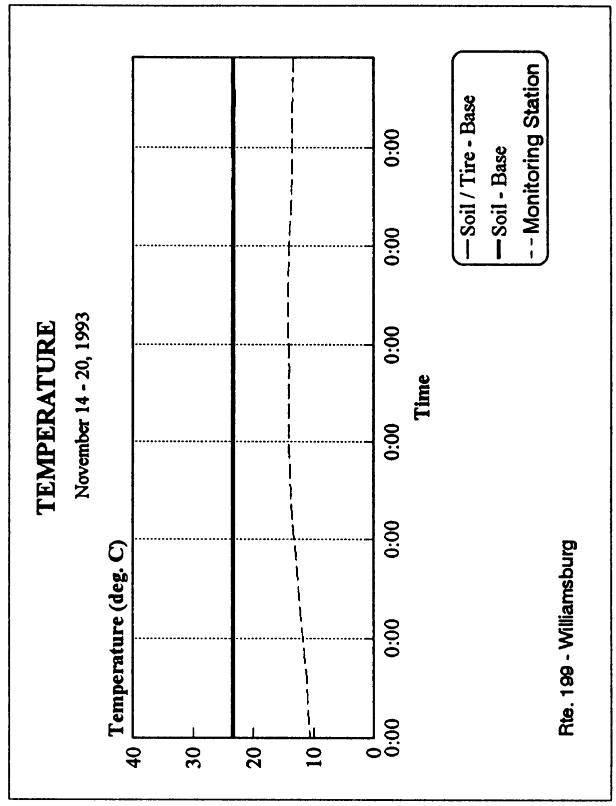

VERTICAL STRESS AT BASE OF EMBANKMENT
November 7 - 13, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
— Soil/Tire — Soil
Rte. 199 - Williamsburg


TEMPERATURE
November 7 - 13, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
— Soil/Tire - Base
— Soil - Base
- - Monitoring Station
Rte. 199 - Williamsburg


SHREDDED-TIRE EMBANKMENT SETTLEMENT
November 14 - 20, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg


SOIL EMBANKMENT SETTLEMENT
November 14 - 20, 1993
Settlement (mm)
0
-50
-100
-150
-200
0:00
Time
Base
Top
Rte. 199 - Williamsburg


VERTICAL STRESS AT BASE OF EMBANKMENT
November 14 - 20, 1993
Pressure (kPa)
100
80
60
40
20
0
0:00
Time
Soil/Tire
Soil
Rte. 199 - Williamsburg


TEMPERATURE
November 14 - 20, 1993
Temperature (deg. C)
40
30
20
10
0
0:00
Time
Soil / Tire - Base
Soil - Base
Monitoring Station
Rte. 199 - Williamsburg